APPLICATION OF HOLOGRAPHIC INTERFEROMETRY TO THE INTERIOR BALLISTIC FLOW FIELD IN THE BARREL OF A TWENTY MILLIMETER CANNON

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THESIS

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by

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Application of Holographic Interferometry
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the Barrel of a Twenty Millimeter Cannon

by

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LIST OF SYMBOLS

SYMBOL	DEFINITION
A	Cross-section area
C	Constant specifying thickness of shock region
E	Specific internal energy
j	Mass point number
M	Mass
P	Pressure
q	Artificial viscosity
t	Time
u	Velocity
V	Specific Volume
X	Eulerian Position
ρ	Density

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I. INTRODUCTION

For many years the field of theoretical interior ballistics was almost entirely confined to a single problem: given the characteristics of shot, charge, and gun, to calculate the muzzle velocity and peak pressure. (Ref. 1)

With the discovery of the laser and its application to holography, more interesting information can be obtained. It is possible to make a hologram of the projectile and its flow field, then reconstruct the image with exact detail.

Having a thorough knowledge of the physical characteristics of the internal gas flow field is essential in ballistic design. Although thermochemical constants for the products of combustion during actual gun firing are not well known, it is assumed that the gas and the solid grains move together as a homogeneous mixture. If this is true, then the conclusions of the Lagrange hypothesis are applicable to the interior ballistics of a gun.

The motion of the projectile creates a system of rarefaction waves in the breech, with relaxation occurring through the mechanisms of stress transfer in the bed and in the propellant gas. The dual wave system will accelerate the gas and the particles in the direction of the projectile

motion at the expense of stored internal energy. The more volatile gas will follow the projectile more readily than the particles. With progressive motion of the projectile, the initial unsteady flow may be expected to damp out and, as the motion evolves, to assume the quasi-equilibrium character of the Lagrange solution. This is a flow in which the mixture has uniform density, a linear velocity distribution and a quadratic pressure distribution. Eventually, the propellant is consumed entirely. Subsequent motion involves only the propulsion of the projectile by the reservoir of energetic gas. (Ref. 2)

It is the purpose of this investigation to utilize laser techniques and observe this flow field responsible for propelling the projectile as it transits through the barrel of a gun.

II. HOLOGRAPHIC INTERFEROMETRY

Holography is a process which is similar to photography in certain respects, but is nonetheless fundamentally different. Photography provides a method of recording the two-dimensional irradiance distribution of an image. Generally speaking each "scene" consists of a large number of reflecting or radiating points of light. The waves from each of these elementary points all contribute to a complete wave which we call the "object wave." This complex wave is transformed by the optical lens in such a way that it forms an image of the radiating object. It is this image which is recorded on the photographic emulsion.

Holography is quite different. With holography one actually records the object wave itself. This wave is recorded in such a way that subsequent illumination of the record serves to reconstruct the original object wave even in the absence of the object. A visual observation of this reconstructed wavefront then yields a view of the object or scene which is practically indiscernible from the original.

The method of recording the object wave is as follows. One starts with a single monochromatic beam of light which

has originated from a very small source. The requirement of coherence means that the light should be capable of displaying interference effects that are stable in time. This single beam of light is then split into two components, one of which is directed toward the object or scene; the other is directed to a suitable recording medium. The component beam that is directed to the object is scattered, or diffracted, by that object. This scattered wave constitutes the object wave, which now is directed to the recording medium. The wave that proceeds directly to the recording medium is the reference wave. Since the object and reference waves are mutually coherent, they will form a stable interference pattern when they meet on the recording medium. The detailed permanent record of this interference pattern on the recording medium is called the "hologram." This method is illustrated in Figure 1. When the hologram is illuminated with a beam of light which is similar to the original reference wave used to record the hologram, light will be transmitted only through the clear areas, resulting in a complex transmitted wave. Because of the recorded interference fringes, this wave conveniently divides into three separate components, one of which exactly duplicates the original object wave. By viewing

this reconstructed wavefront, one sees an exact replica of the original object. Three-dimensional images of opaque objects may be reconstructed and photographed from different viewing angles using a single hologram.

The above description of holography can be represented mathematically as follows:

Let $\quad \overline{E} = \overline{O} + \overline{R} \qquad\qquad$ 2.1

Where $\quad O$ represents the object or scene beam

$\qquad\quad R$ represents the reference beam

Then $\quad E^2 = O^2 + R^2 + 2\langle \overline{O} \cdot \overline{R} \rangle \qquad\qquad$ 2.2

Taking the time average:

$$\langle \overline{E}^2 \rangle = I = I_O + I_R + 2\langle \overline{O} \cdot \overline{R} \rangle \qquad 2.3$$

The term $2\langle \overline{O} \cdot \overline{R} \rangle$ in equation 2.3 is the interference term. Without interference the intensity of the two beams are merely additive. With the utilization of monochromatic light derived from a single ideal source, interference is always possible.

Uncorrelated light beams, as from two different light sources, are uncorrelated and are called incoherent. Coherent radiation produces interference effects. The superposition of incoherent radiation yields the addition of the intensities of the object and reference beams.

The interference term contains both amplitude and phase information. Consider two waves such that:

$$\overline{O}\cdot\overline{R} = \tfrac{1}{4}(\overline{O}e^{-i\omega t} + \overline{O}^{*}e^{i\omega t})\ (\overline{R}e^{-i\omega t} + \overline{R}^{*}e^{i\omega t}) \qquad 2.4$$

Then

$$\overline{O}\cdot\overline{R} = \tfrac{1}{4}\left\{\overline{O}\cdot\overline{R}e^{-2i\omega t}+\overline{O}^{*}\overline{R}^{*}e^{2i\omega t}+\overline{O}\cdot R^{*}+O^{*}\cdot R\right\} \qquad 2.5$$

$$2\langle\overline{O}\cdot\overline{R}\rangle = \tfrac{1}{2}(\overline{O}\cdot\overline{R}^{*} + \overline{O}^{*}\cdot\overline{R}) \qquad 2.6$$

If $O_1 = O_1e^{ig_1}$ etc. and $R_1 = r_1e^{ih_1}$

$$2\langle\overline{O}_1\cdot\overline{R}_2\rangle = O_1r_1\mathrm{COS}(g_1-h_1) + O_2r_2\mathrm{COS}(g_2-h_2)$$

$$+ O_3r_3\mathrm{COS})g_3-h_3) \qquad 2.7$$

Thus the interference term contains both amplitude and phase information. From equation 2.6 it is evident that interference occurs only when light beams of the same polarity interact with one another.

The complete interference equation is:

$$I = \langle\overline{E}^2\rangle + I_R + I_O + R\cdot O^{*} + O\cdot R^{*} \qquad 2.8$$

where $\langle R\cdot R^{*}\rangle = I_R$

and $\langle O\cdot O^{*}\rangle = I_O$

The reconstruction process can also be described with equation 2.8. The amplitude transmittance of the hologram

is assumed to be proportional to the intensity

$$t(x) + KI \qquad 2.9$$

On reconstruction with the reference beam R, the following is obtained:

$$R \cdot KI = R(I_R + I_O) + R \cdot R \cdot O^* + R \cdot R^* \cdot O \qquad 2.10$$

The last term in equation 2.10 is the reconstructed object beam.

A primary consideration in the technique of holographic interferometry of flow fields is the source of coherent light. The Q-switched ruby laser has proved to be an excellent light source for these applications. It provides the high power necessary to expose the plate in a time frame suitable for freezing the motion of the flow field.

The wavelength of this laser is 6943 Å, which is compatible with AGFA-GEVAERT 10E75 holographic film plates. (Ref. 3)

III. EXPERIMENTAL LAYOUT

A. GENERAL PHYSICAL ARRANGEMENT

The experiment was conducted at the Naval Postgraduate School Rocket Laboratory. The laboratory contained four test cells measuring 12' X 17' with reinforced concrete walls 12" thick. A control room with observation windows was located directly behind the test cells.

The 20mm cannon was mounted horizontally on a rocket test stand. Two steel mounts were used to secure the barrel in place at a height of 6.5 inches from barrel center line to the top of the test stand.

Two large wooden tables were constructed and placed parallel to and on either side of the test stand. The tables provided a platform for the optical equipment necessary to obtain holograms. The tables were rigidly fastened together; however, they were completely isolated from the test stand to ensure stability during cannon operation. Furthermore, plywood boxes were constructed to fit over the tables and completely house the optical equipment. The plywood boxes not only acted as protection for the equipment but also acted as a light shield for the

holographic process. The tops of the plywood boxes were hinged in order to allow easy access to the optical equipment.

The muzzle of the cannon faced a bullet trap located 13 feet outside the test cell. The bullet trap contained an 18" X 18" X 1½" armored plate, tilted 45° from the path of the projectile, and a sand trap measuring 5' X 5' X 2½'.

Upon bullet impact, the plate shattered the projectile and deflected the fragments into the sandtrap. In order to provide additional safety, the entire sandtrap was housed inside a steel turret for a 5" gun mount measuring approximately 15' X 20' X 10'.

An electrical firing mechanism was placed at the breech end of the cannon. The firing sequence was directed from the control room.

A light shield was provided to cover the observation window during placement and removal of the holographic plates.

The ruby laser and its components were fixed in position in a test cell adjacent to the cell housing the 20mm cannon. The purpose of this placement was necessary not only for space consideration but mostly for protection of the instrument. A specially constructed table provided support for the laser rail system. The laser was placed normal to the

wall separating the two cells. (Figure 2) A 2-inch hole was drilled through the concrete wall to allow beam passage. A water source for the laser head and output etalon cooling system was incorporated within the test cell. The laser was equipped with a remote control making it possible to fire either from the test cell or the control room. (See Figure 3)

B. BARREL INSTRUMENTATION

For viewing the projectile inside the cannon a .817" diameter hole was drilled completely through the barrel 4.5" from the muzzle. In order to preserve the integrity of the barrel, projectile and flow field, plexiglass windows were designed to seal the port and provide observation inside the barrel. (See Figure 4)

The windows were milled from optical quality 3/4" plexiglass. Two windows were pressure tested in a simulated barrel to 6000 PSI, thus ensuring strength capabilities necessary to withstand internal pressures present. (See Figure 5)

Figure 6 shows the design consideration met for mounting the windows in the barrel. Figure 7 shows the actual barrel with window and with collar.

Figure 8 shows the collar device used to secure the windows in the barrel.

A Kistler 607A pressure transducer was installed 5.5 inches from the breech end of the barrel. This location was just ahead of the tip of the projectile prior to firing. The signal from the transducer was relayed to a Kistler model 504 universal charge amplifier located in the control room. The signal from the charge amplifier was passed to a Textronix 549 storage oscilloscope. The oscilloscope allowed the signal to be time delayed by a predetermined amount and then amplified to +30 volts, which in turn was used to trigger the xenon flash tube of the Korad K-1 pulsed ruby laser.

A Kistler 603H pressure transducer was located 2.5 inches aft of the observation ports. The signal from the transducer was relayed to a Kistler model 504A universal charge amplifier located in the control room. The signal from the charge amplifier was passed to a Hewlett Packard Model 214A pulse generator where it could be delayed and amplified. The resulting pulse was used to energize the Pockel cells of the Korad K-1 pulsed ruby laser.

The muzzle velocity was measured by the use of two Oehler Model 55 ballistic velocity screens. The screens

were mounted 4 feet apart and placed 81.25 inches from the muzzle of the cannon. As the projectile passed through each screen a 12-volt pulse with an adjustable 2-8 millisecond pulse length was produced and relayed to an Oehler Model 21 chronograph. The two pulses provided a start and stop for the chronograph. Tables of velocities were provided for known screen separation. (See Figure 9)

C. OPTICAL SYSTEM

Figure 10 shows the optical layout used to accomplish the holography. The Korad K-1 pulsed ruby laser was used for the holography process. By utilizing the laser system in the Q-switch mode of operation, high power single transverse mode output could be obtained. A Pockel cell was used to achieve the Q-spoiling required for peak output power.

When operating the Korad K-1 pulse ruby laser in the tem_{00} mode a peak power of 2.5 megawatts with pulse energy of .050 joules over a pulse width of 20 nanoseconds can be realized. The output beam measured approximately 2mm in diameter at a wavelength of 6943Å with a coherence length that exceeds one meter. Figure 3 shows a photographic view of the laser installation.

The laser beam passes through a 2-inch hole in the concrete wall then through another 2-inch hole in the plywood boxes where it first contacts a narrow-band filter which removes the undesired light from the xenon flash tube. The beam then strikes a 2-inch round beam splitter where it is divided into two wave fronts, a scene beam and a reference beam. The intensity of the reference beam is about twice that of the scene beam.

The scene beam is directed along the centerline of a 2.5 meter optical bench where prior to striking mirror #1 it passes through a collimating lens, double concave lens and another collimating lens.

The lens arrangement was designed to allow the scene beam to be expanded to a diameter compatible with the hole drilled through the barrel of the 20mm cannon.

Mirror #1 directed the beam through the windows in the 20mm cannon and onto mirror #2. In order to accomplish this, 3-inch holes were cut in the plywood boxes to permit the beam to pass, allowing enough tolerance for adjustment to ensure that the beam passed through the windows normal to the cannon's axes. Furthermore, mirror #1 was secured to a gimbal mount which allowed a fine adjustment to be made in the horizontal and vertical axes.

Mirror #2 directed the scene beam down the centerline of a 1.5 meter optical bench where a second narrow-band filter was located to remove the unwanted flash from the cannon blast. The beam then proceeds through an expanding collimating lens to mirror #3 where it is directed to the holographic plate. The location of the expanding collimating lens makes it possible to enlarge the scene beam from test section (window size) diameter to a diameter of approximately 4-inches.

After passing the beam splitter the reference beam proceeded to mirror #4 on a 2.0 meter optical bench. The physical arrangement allowed the reference beam to be adjusted to the same length as the scene beam. Mirror #5 directs the beam through two series of expanding--collimating lenses which enlarged the reference beam to approximately 4-inches in diameter at the holographic plate.

Throughout the entire system the optical benches were bolted to the tables on specially designed cross feet which allowed the system to be leveled by adjustment knobs located at each crossfoot. The alignment procedure was greatly simplified by the use of mirrors which contained screw type adjustments for vernier-scale movement about the horizontal and vertical axes. In addition, all the optical components

could be easily positioned along the optical bench. Figure 11 shows the actual optical layout with one plywood box removed to show the arrangement.

The alignment of the system was accomplished by the use of a coherent radiation 3-milliwatt helium-neon continuous wave laser. This laser was mounted on a stand which was placed perpendicular to the axis of the ruby laser cavity. By firing the ruby laser on an exposed polaroid paper a "spot" could be obtained which was used in the alignment process. By placing a mirror at a 45° angle in the ruby laser cavity, the CW beam could be directed through the cavity and centered on the "spot." This centered beam would then coincide with the ruby laser beam and the optical system could be accurately aligned.

IV. FIRING SEQUENCE

All the electrical equipment was turned on to allow the required warm-up time while the test section and optical system were being prepared and aligned. The barrel test section assembly required particular care when installing the plexiglass windows, to ensure that the faces were parallel to the center line of the cannon and normal to the laser beam's path.

After the system was aligned, all electrical equipment was checked for proper settings and all timers zeroed. The opening into the plywood box containing the holographic plate was covered and the alignment mirror removed. The test cell was closed and a holographic plate was placed in its holder. The test cell door was raised to a level just above the muzzle of the 20mm cannon. At this time the cannon was loaded.

The individual who was loading the cannon and connecting the firing mechanism carried with him a safety key which broke the firing circuit at the control panel to prevent accidental firing prior to his clearing the test area. Following loading, the opening into the plywood box

containing the hologram was uncovered and control was then commenced from the control room. All electrical equipment was scanned and the warning horn sounded to alert personnel of the impending shot. The firing sequence was then initiated. A schematic of this sequence is shown in Figure 12.

The charge switch for the laser capacitor was activated. While the capacitor bank was charging, the safety key was installed in the fire control panel and power supplied to the firing mechanism. When the laser ready light illuminated the firing mechanism, capacitors were charged and the cannon fired. Figure 13 shows a view of the control room and monitoring equipment.

The firing process was observed through the observation window. A light shield was placed against the window after firing to protect the hologram from unwanted illumination.

Actual bullet movement was used to fire the laser. On initial firing, a pulse from the Kistler transducer located at the breech was passed to the Textronix 549 storage oscilloscope, where it was delayed and amplified, then used to trigger the xenon flash tube of the Korad K-1 pulsed ruby laser. Considering that the pumping time for the laser is approximately 1000 microseconds and that

approximately 1500 microseconds are needed for projectile travel to the test area, 500 microseconds was used for the pulse delay.

When the projectile reached the second Kistler transducer another pulse was initiated that was relayed to a Kistler model 504A charge amplifier then to a Hewlett Packard Model 214A pulse generator. The pulse generator provided the voltage necessary to trigger the Pockel cell of the Korad K-1 pulsed ruby laser. This unit allowed for a variable signal delay which was used to adjust the time interval for laser firing. Two Monsanto Model 101B timers were incorporated into the system at various locations to provide checks on intervals of interest. Also a Korad KD energy monitor was employed to check the actual laser firing interval.

After firing, the test cell was closed and the hologram removed for processing. The armor plate was inspected for integrity and repositioned if necessary. The 20mm cannon was unloaded and the windows removed and examined for damage.

V. HOLOGRAPHIC FILM AND PROCESSING TECHNIQUE

The Korad K-1 pulsed ruby laser delivered a beam at a wavelength of 6943Å. In order to minimize the effects of extraneous light leakage into the system a photographic emulsion with narrow band sensitivity centered in this region was selected. Agfa-Gevaert 10E75 holographic plates were found to be the most suitable for this purpose. This film has a resolution capability of 2800 lines per mm. For holograms produced with 6943Å light this is nearly the required maximum resolution. Reference 4 gives a spectral sensitivity curve for the emulsion.

Following exposure to the laser light the hologram plate was removed from its holder and placed in a closed container and taken to a dark room for development. The initial processing required a five minute bath in kodak D-19 developer. The entire five minute bath was completed in total darkness. Then the plate was rinsed and placed for five minutes in a standard fixer. After 30 seconds in the fixer it was permissible, although not necessary, to turn on green photographic lights in the dark room. From the fixer the plate was washed in water for five minutes and then allowed to air dry. During the entire development

procedure, when it became necessary to touch the hologram it was handled by the edges in an attempt to keep the hologram clear of unwanted finger markings.

When using the 20-nanosecond ruby pulse, it was not possible to control exposure time. Therefore, to ensure the desired intensity, a combination of suitable neutral density filters were placed in the beam paths.

VI. RECONSTRUCTION

To reconstruct the holograms a 15-milliwatt Spectra Physics continuous wave, helium-neon laser was used for the reconstructing wave. A Spectra Physics collimator was fastened to the laser, causing the beam to be expanded to approximately four inches in diameter. The beam was directed to pass through the hologram as outlined in Part I. The converging real image was then photographed with a single reflex polaroid camera using type 55 positive-negative film. This film has a resolution capability of 150-165 lines per mm negative, 14-17 lines per mm positive, thus providing excellent results. The reconstruction process is illustrated in Figure 14. The negatives were further processed at the Naval Postgraduate School photo lab, from which prints were produced.

VII. COMPUTER PROGRAM FOR PREDICTIONS OF FLOW PARAMETERS

The computer program used to predict the velocity of the projectile, pressure and total energy of the flow field was an adaption of a program developed at the Naval Ordnance Laboratory. The program was originally concerned with the analysis of hypervelocity model launchers (Ref. 5). The method of analysis used was essentially a one-dimensional, Lagrangian scheme where the field was divided into six regions each of which in turn was divided into zones. At the interface of each zone mass points were inserted. Each mass was considered to consist of one-half of the mass of the adjacent zone. The hydrodynamic equations, in finite difference form, were then applied to each mass point during the particular interval of interest. The method employed was the "q" method of Von-Neumann and Richtmyer (Ref. 6 and 7).

The following equations were used for this method:

Isentropic flow energy equation;

$$\frac{\partial E}{\partial t} = -(P+q)\,\frac{\partial v}{\partial t}$$

Equation of motion;

$$\frac{\partial u}{\partial t} = -\,\frac{\partial (P+q)}{\partial x}\quad \frac{1}{M}\,A(x)$$

Equation of state;

$$P = P(E,v)$$

$$M = \int^{X} (X)A(X)\,dx$$

$$\text{with} \quad \begin{cases} \dfrac{Co^2}{v}\dfrac{\partial u}{\partial y} & , \dfrac{\partial u}{\partial y} < 0 \\ 0 & , \dfrac{\partial u}{\partial y} \geqslant 0 \end{cases}$$

The artificial viscosity term "q" was added to the pressure term in the energy and motion equations in order to spread variable changes created by the shock over a finite region. This allows the equation variables to be considered continuous across the shock. The constant Co permits adjustment of the shock "thickness."

The equations were written in finite difference form with initial values of Eo, Po, and Vo being provided for each region. In order to maintain stability during the process, a new time increment was calculated for each cycle.

During each cycle the pressure was calculated at each mass point using the equation of state and energy. The differential in pressure between mass points was then applied to the equation of motion to determine the acceleration and velocity of each mass point.

For each region it is necessary to input the initial temperature, pressure, molecular weight and a geometrical description.

The program was written in FORTRAN. A listing of the program and the input is given in Appendix A.

VIII. HOLOGRAPHIC RESULTS

Initially the first few holograms obtained appeared to be in the region several centimeters in front of the projectile. However, when further experimental studies did not give the desired results, an investigation was initiated to examine the laser system. It was then discovered that a short circuit had occurred between the plate and cathode of the large thyratron of the Korad power supply. This short circuit would occur approximately 8 minutes following the application of power. This malfunction caused a firing pulse to be continually delivered to the Pockel cell; thus, nearly two-thirds of the seventy-five test firings resulted in holograms in which the laser had fired from 50 to 200 microseconds early. To further compound the problem the Korad KD energy monitor was not available to confirm actual laser firing.

With the incorporation of the energy monitor into the system, and careful monitoring of the power supply, several good holograms were obtained. Figure 15 shows a series of compression waves approximately 2 cm in front of the projectile. Figure 16 shows these same type of waves

approximately 1 cm in front of the projectile. A traveling bow wave can be seen in Figure 17. It is believed that this wave is approximately 3 mm in front of the projectile.

Due to time consideration allowed for this study, the area just behind the projectile was not captured; however, Figure 18 shows a hologram obtained approximately 30 microseconds following projectile passage through the test area. The effects of powder blast not only etch the plexiglass windows but also leave a carbon deposit over the inner faces, resulting in a clouded view of the test area. Further investigations will determine if this powder blast is directly behind the projectile or if there are several microseconds delay between the gas particles and the projectile.

IX. COMPARISON OF ANALYTICAL AND EXPERIMENTAL RESULTS

Analytical results were obtained previously by Robert G. Bettinger (Reference 8) during his work concerning gas core characteristics in the muzzle environment of the 20mm cannon.

Figures 19 and 20 are outputs obtained by Bettinger. Figure 19 summarizes the major input data and initial conditions required, and demonstrates the output format used for representing these data. As shown in Figure 19, a printout was obtained every 0.2 milliseconds. Figure 20 illustrates the output obtained just as the projectile exits the barrel; at this time a muzzle velocity of 1064 meters per second was obtained.

It must be emphasized that the program (Reference 5) does not take into consideration the effects of frictional forces on the projectile. Therefore, in order to obtain a more realistic solution either the program must be modified or the powder parameters altered to account for this constraint. Figures 19 and 20 resulted from the latter choice.

In order to verify these results it was necessary to analyze the powder used to propel the 20mm projectile.

The type powder used in the 20mm cartridge was WC870 with a charge weight of 590 grains. WC870 is a sphere of .305" average grain diameter, with a specific gravity of 1.56 grams/cc. A representative composite is:

Nitrocellulose (13.15%N)	=	81.49%
Nitroglycerine	=	10.0 %
Dibutylphthalate	=	5.5 %
Diphenylamine	=	1.0 %
$CaCO_3$	=	0.1 %
AsH	=	0.5 %
Graphite	=	0.15%
Na_2SO_4	=	0.16%
$K2SO_4$	=	0.75%
SNO_2	=	0.75%
Ethyl Acetate	=	0.10%
H_2O	=	0.80%

The percentages are given of the dry weight, so that the sum of the ingredients up to the last two constituents is 100%.

The average thermochemical properties of this composition are (by Hirschfelder's approximation, reference 1) as follows:

T_0	=	$2856^{\circ}K$
n	=	0.04218 grams/mol
γ	=	1.2394
F	=	335068 ft-lbs/md
b	=	0.943 cc/gram

The molecular weight of the constituents can be found directly except for nitrocellulose. The nitrocellulose in propellant compositions varies in its nitrogen content. The cellulose molecule is a large one but, for present

purposes, it can be written $C_6H_7O_2(OH)_3$. On nitration, X(OH) groups are replaced by (ONO_2) groups, the value of X depending on the nitrogen content. The resulting compound is $C_6H_7O_2(OH)_{3-X}(ONO_2)X$. The molecular weight is easily found to be (162.14+ 45X) and, if Y is the percentage nitrogen content, $Y = \frac{1400.8X}{162.14 + 45X}$. This gives $X = \frac{162.14Y}{1400.8 - 45Y}$. Thus for a given nitrogen content Y and X can be calculated and the atomic composition found from:

$$C=\frac{6}{162.14 + 45X} \qquad H=\frac{10-X}{162.14 + 45X} \qquad N=\frac{Y}{1400.8} \qquad O=\frac{5 + 2X}{162.14 + 45X}$$

The heats of formation of the solid propellant can be calculated as outlined in Reference 10.

Inputing the exact values into the computer program resulted in a value of approximately 1463 M/sec. Assuming a projectile drag coefficient of 0.28 (Reference 9), this gives a muzzle velocity of 1036 meters per second which is in excellent agreement with Bettinger's theoretical results.

Furthermore, the maximum possible muzzle velocity (Reference 1) may be calculated from the following:

$$V_m = \frac{2}{\gamma - 1} (RT_0)^{\frac{1}{2}}$$

Using this equation a value of 1097 meters per second is

obtained. The projectile velocity was measured during each firing, and a range of 1020 to 1060 meters per second was obtained.

These values are in excellent agreement with the computer program.

X. SUMMARY AND RECOMMENDATIONS

A considerable amount of difficulty was experienced while attempting to capture the projectile in the test area. Considering the velocity and length of the projectile, passage through the test area occurs within approximately 80 microseconds. Furthermore, considering just the base of the projectile, a time interval of approximately 20 microseconds would result in complete passage of the base of the projectile through the test area. Thus, timing of the laser firing with projectile firing is indeed quite critical.

Referring to Figure 21, it can be seen that the velocity of the projectile approaches a constant value at a distance of approximately 90 cm from the breech of the barrel. It was this fact that prompted the barrel modification to incorporate the pressure transducer near the test area as outlined in Part III Section B. By controlling the firing of the Pockel cell with this transducer, more consistent results were expected.

Theoretically, if the pressure transducer responded instantaneously to the passage of the gas ring of the projectile, the signal produced could be used to pulse the

Pockel cell of the laser just as the nose of the projectile entered the test area.

Unfortunately, 0.5 volts was required to trigger the Hewlett Packard Model 214A pulse generator, while the Monsanto timers responded immediately to projectile passage. Referring to the pressure trace obtained from the pressure transducer (Figure 22), approximately 100 microseconds could pass before the required 0.5 volts was obtained.

In an attempt to confirm the actual passage of the projectile through the test area the pressure transducer was replaced by a temporary contact switch. This switch could only be triggered by actual contact with the gas ring of the projectile. The test confirmed the correct timing of the projectile, agreeing with the results obtained with the pressure transducer as far as the Monsanto timers were concerned.

Due to the fact that most pulse generators require at least 0.5 volts input as a trigger and that the pressure transducer used takes anywhere from 0-100 microseconds to reach 0.5 volts, it is felt that a more positive device must be used to sense the actual position of the projectile. This could be accomplished with a contact switch designed specifically for this purpose.

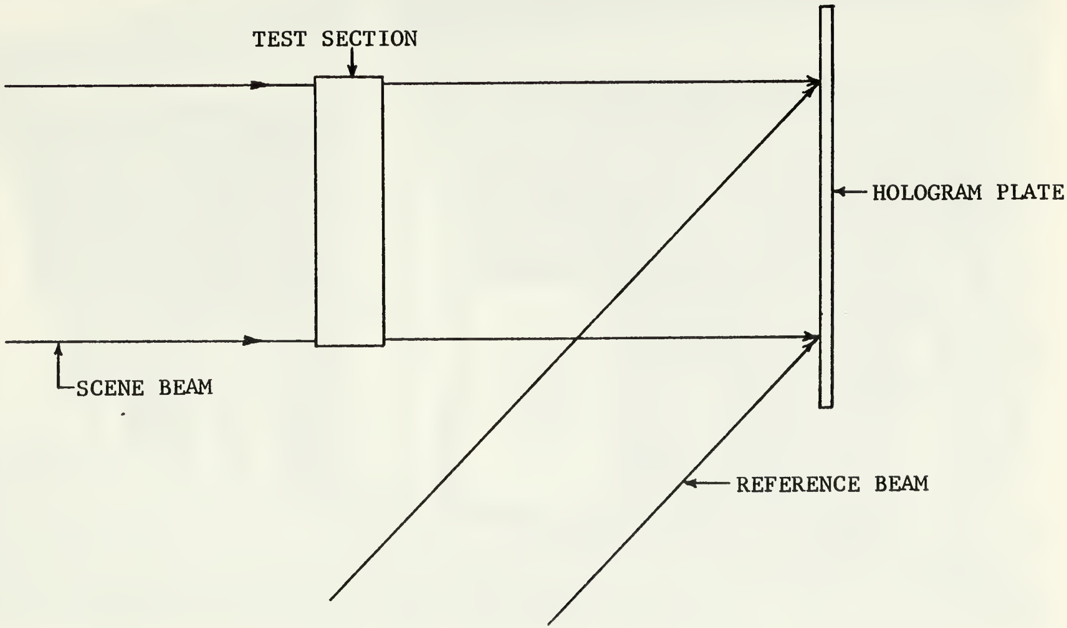
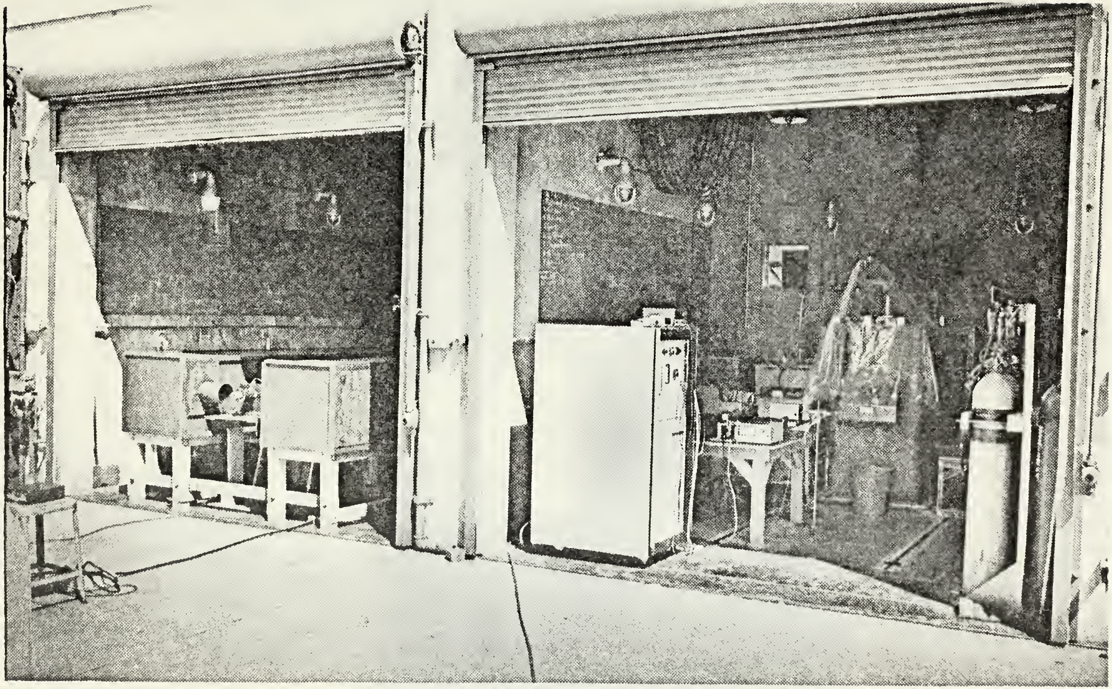


Figure 1. Direct Illumination Method of Obtaining a Hologram



Cannon and Optics Cell Laser Installation

Figure 2

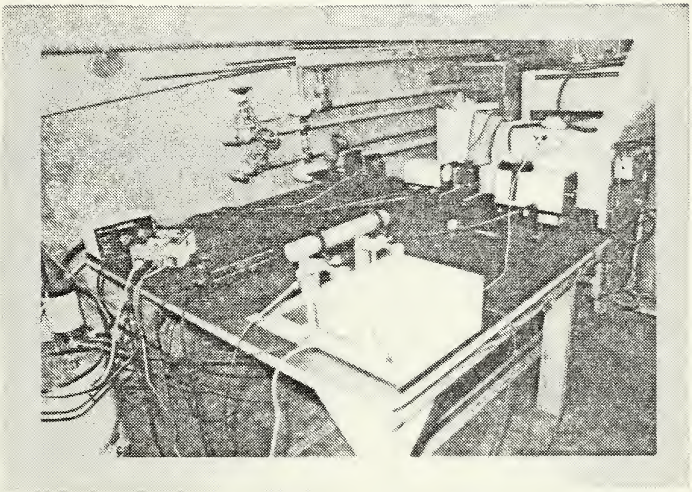


Figure 3. Laser Setup

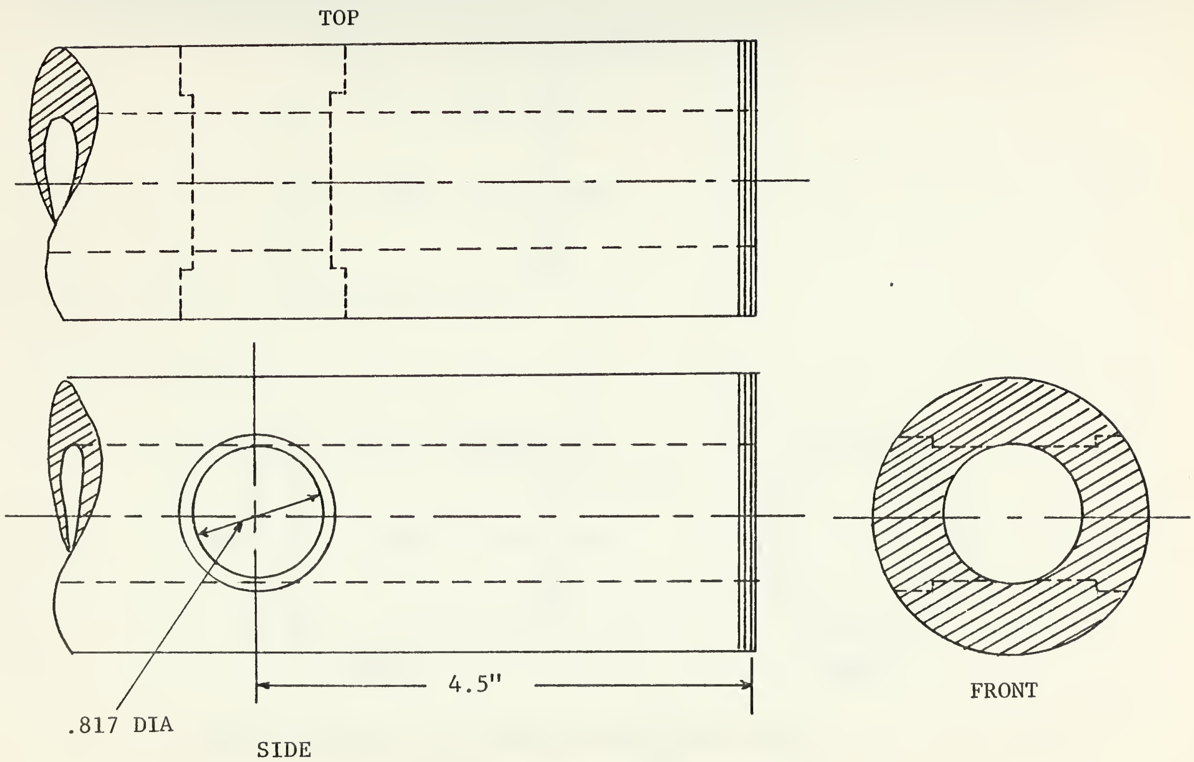
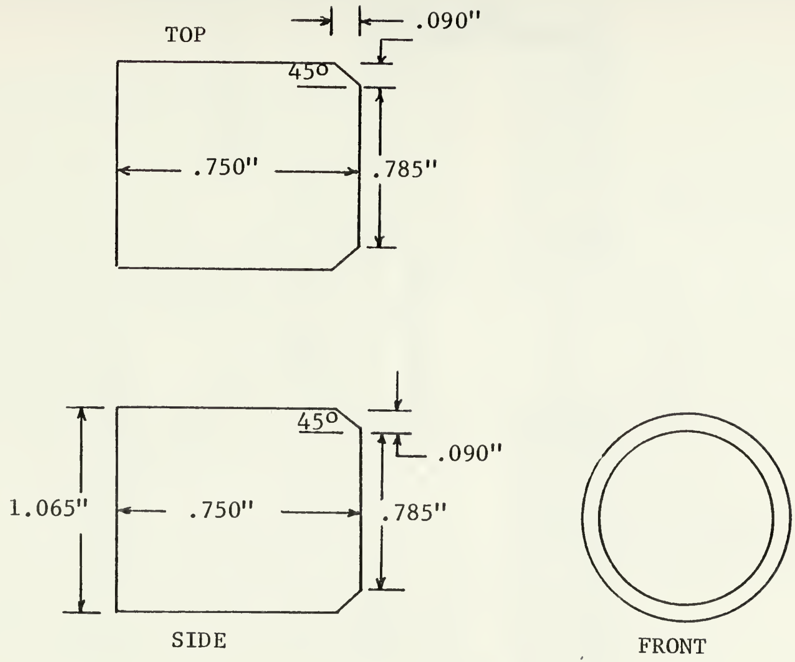


Figure 4. Barrel Design



NOTE: Windows to be seated with #118 O-ring

Figure 5. Plexiglass Windows

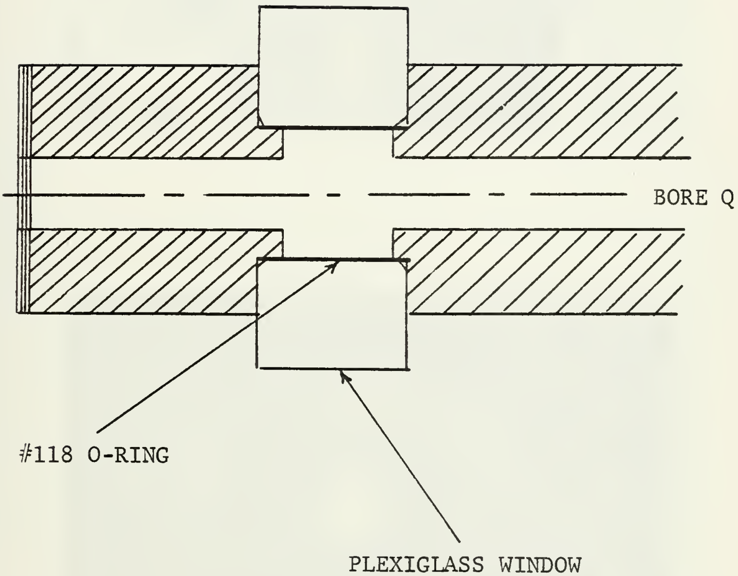


Figure 6.
Top Cutaway View of Barrel with
Plexiglass Window Installation

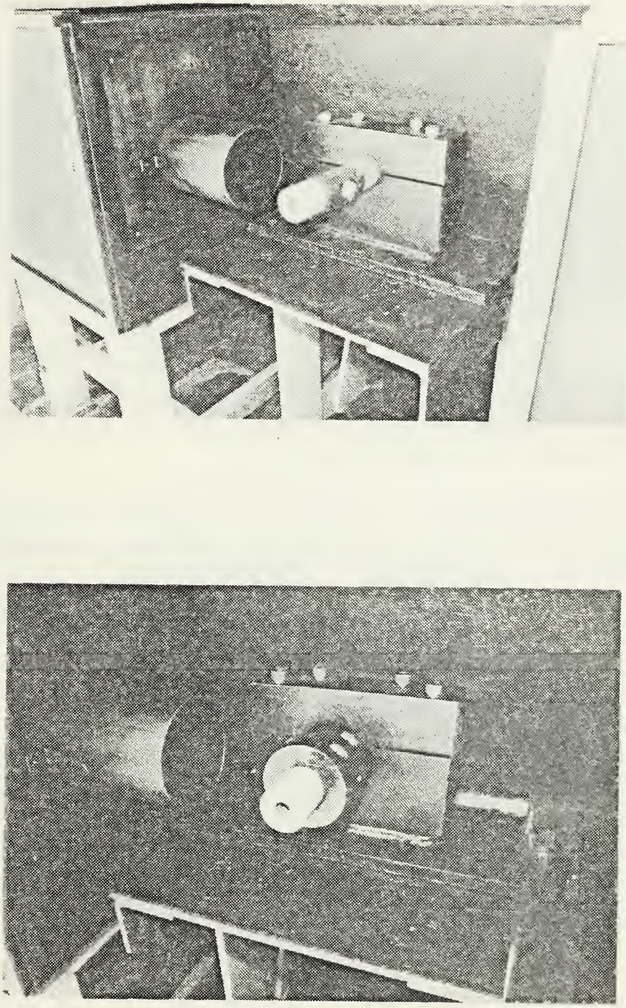


Figure 7. Barrel with Windows and with Collar

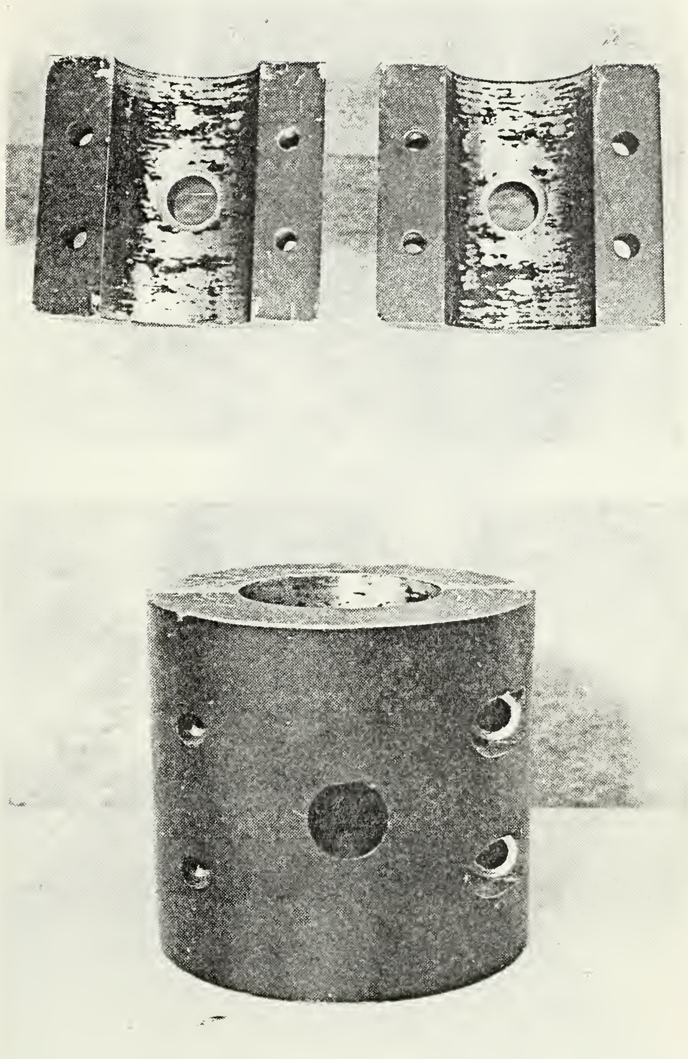


Figure 8. Collar Device

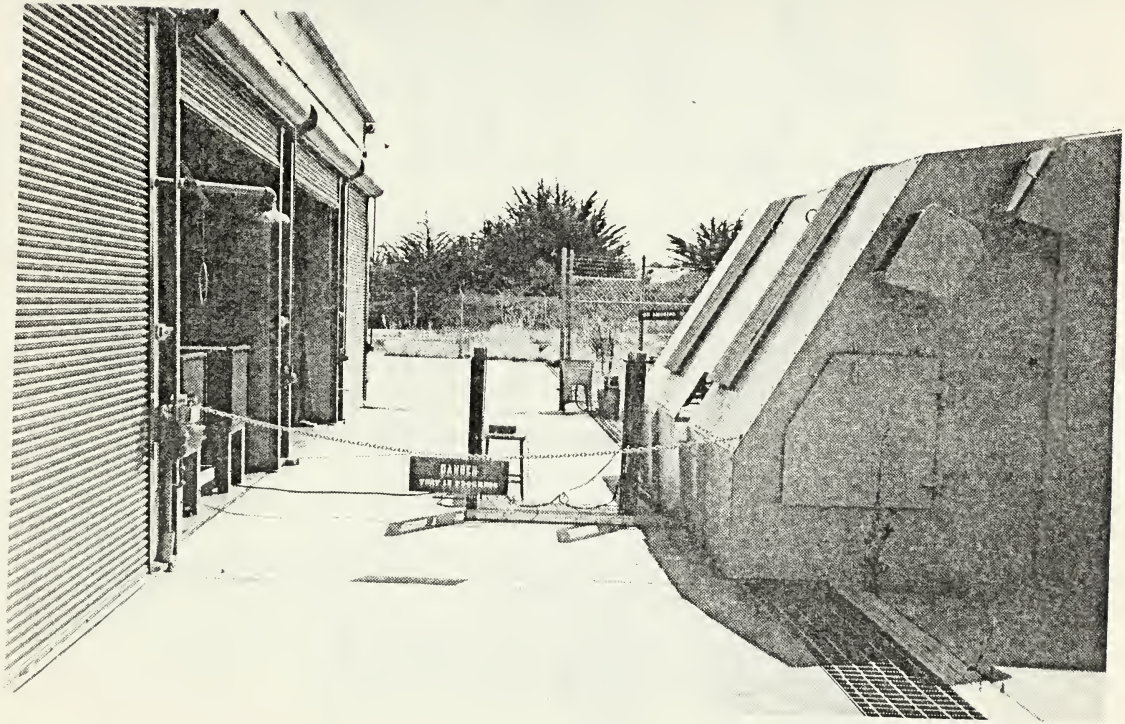


Figure 9. Projectile Path and Turret with Velocity Screen in Place

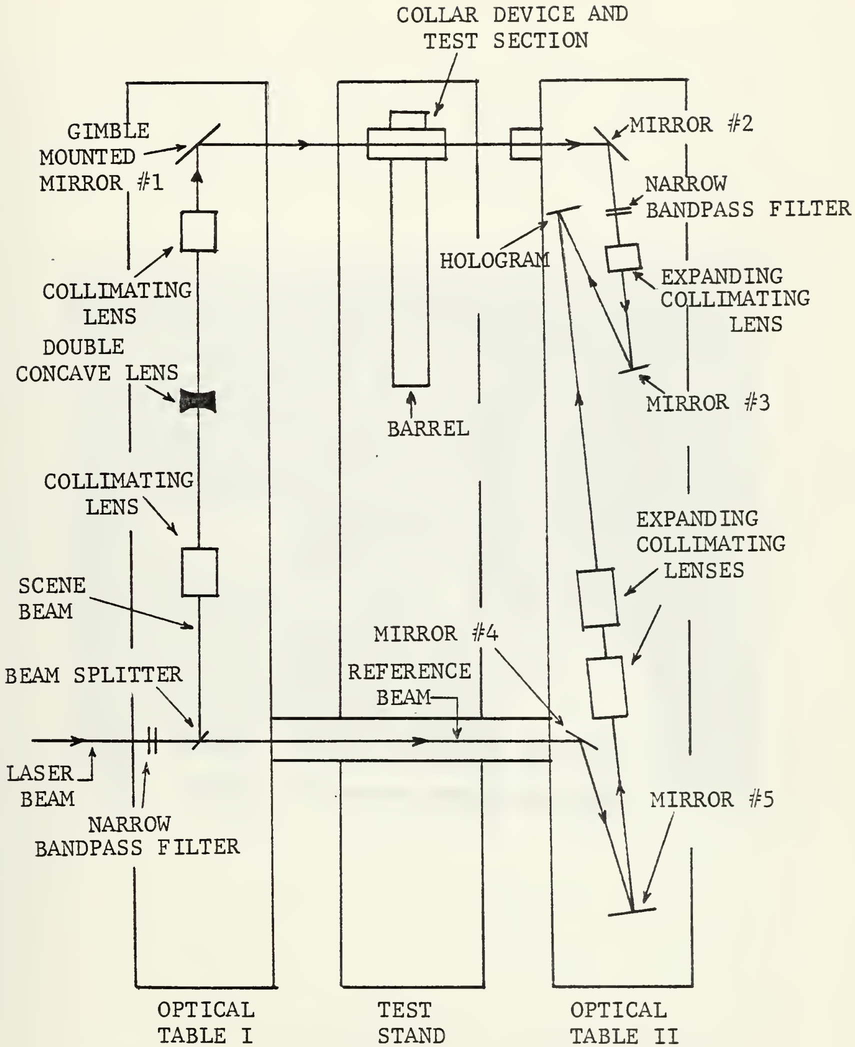


Figure 10. Optical Arrangement

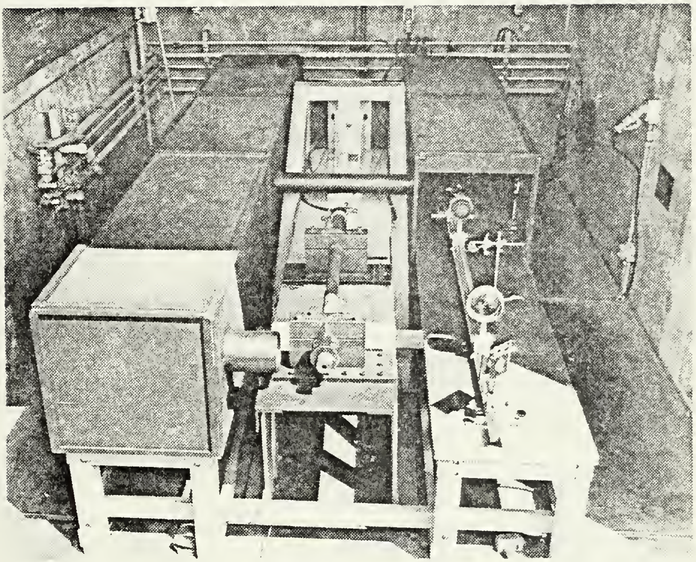


Figure 11. 20mm Cannon with Optical Platform

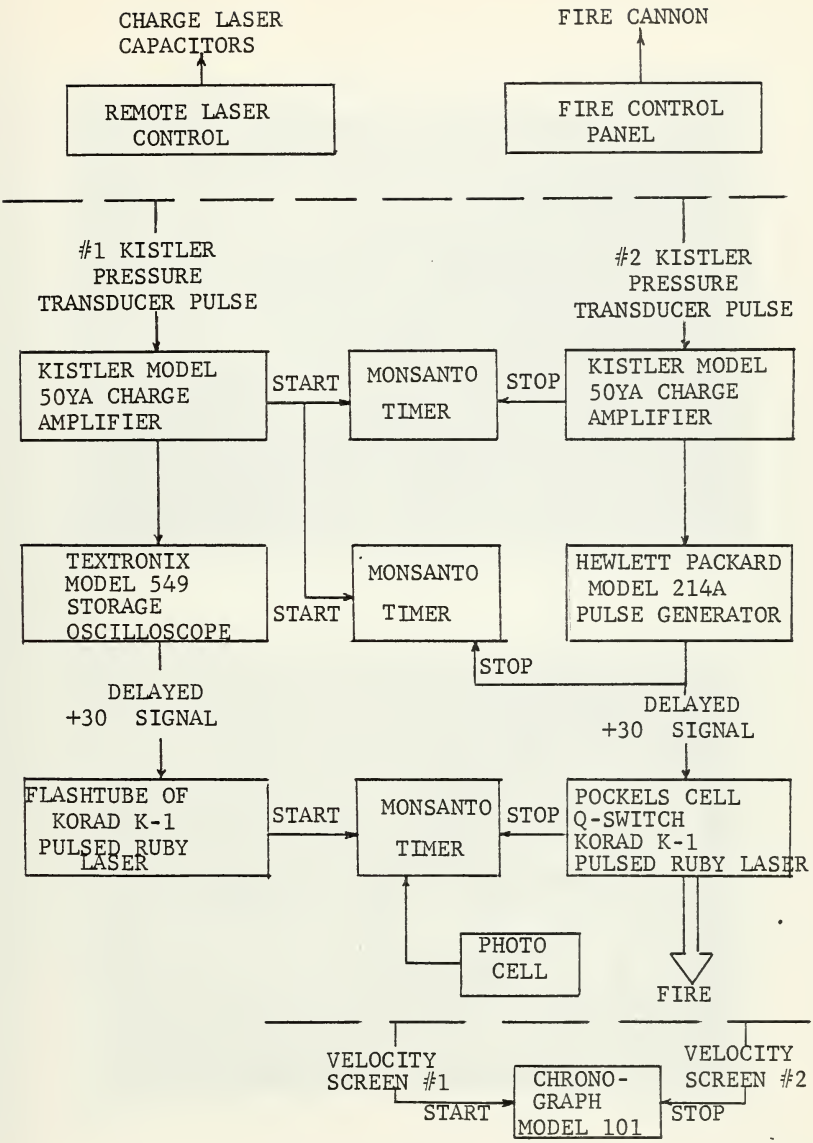


Figure 12. Firing Sequence

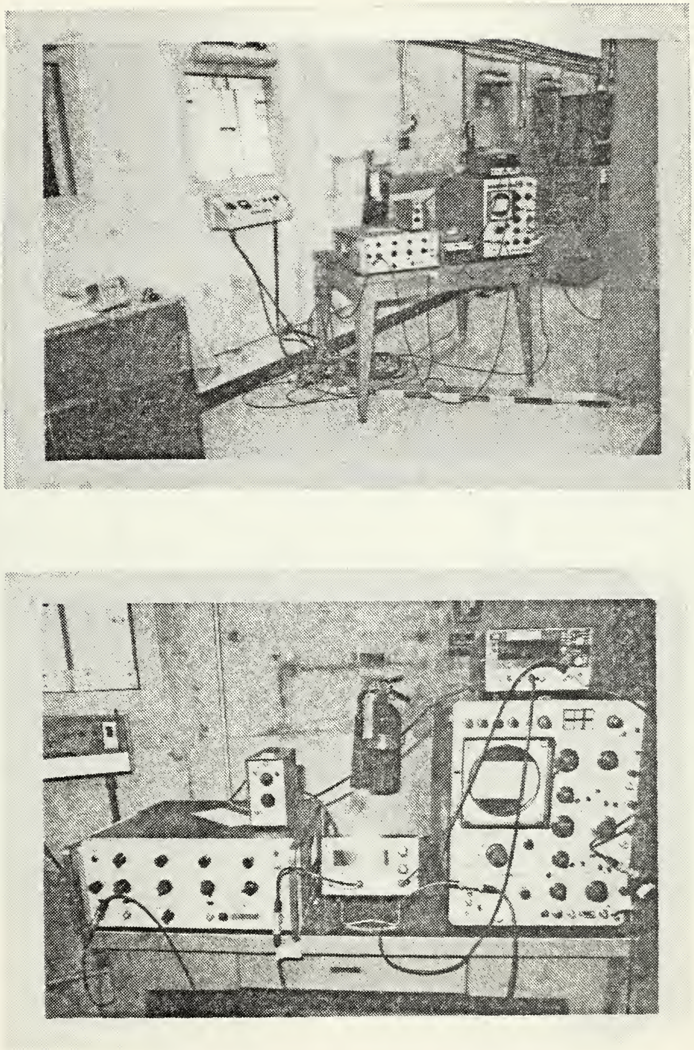


Figure 13. Control Room and Monitoring Equipment

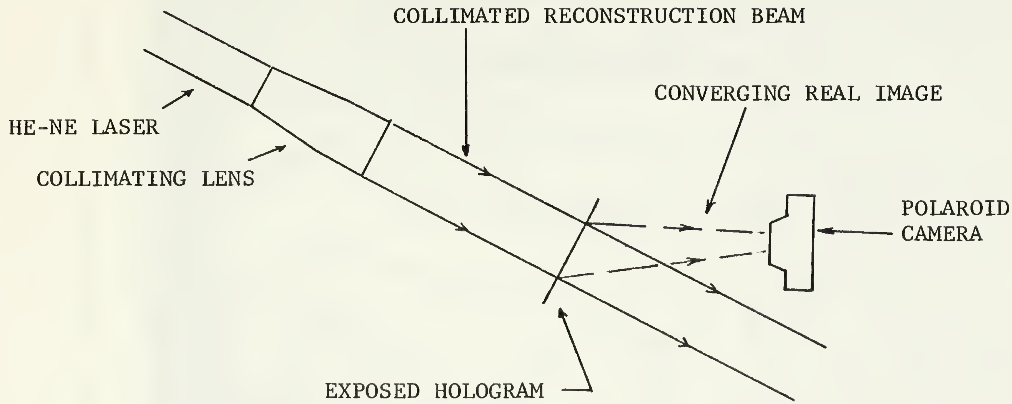


Figure 14. Reconstruction

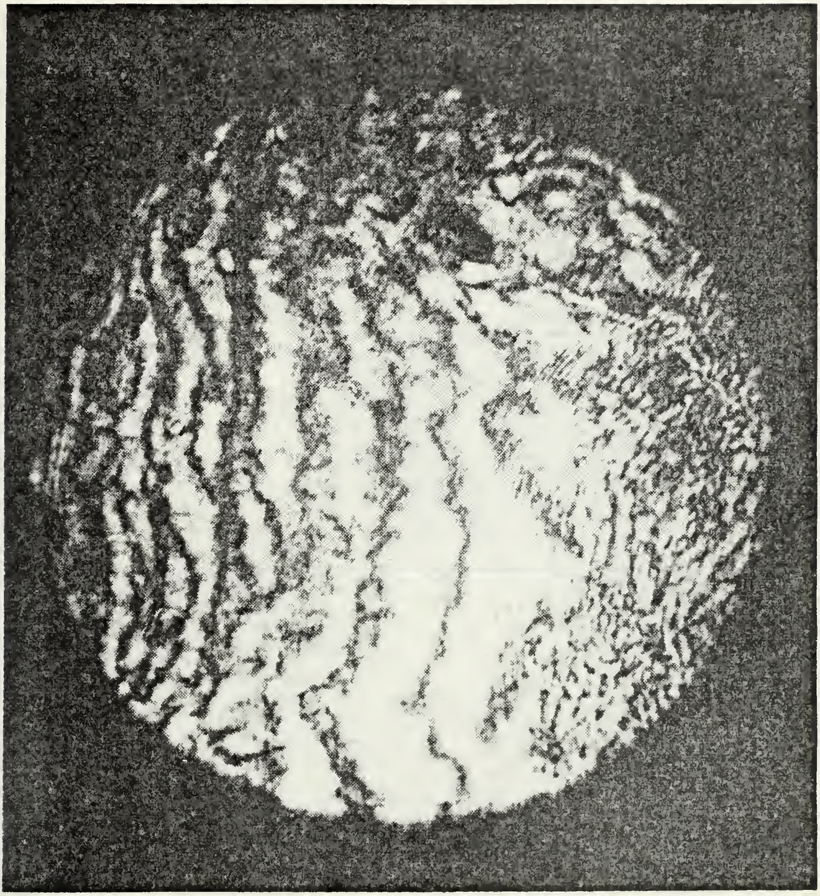


Figure 15. Compression Waves

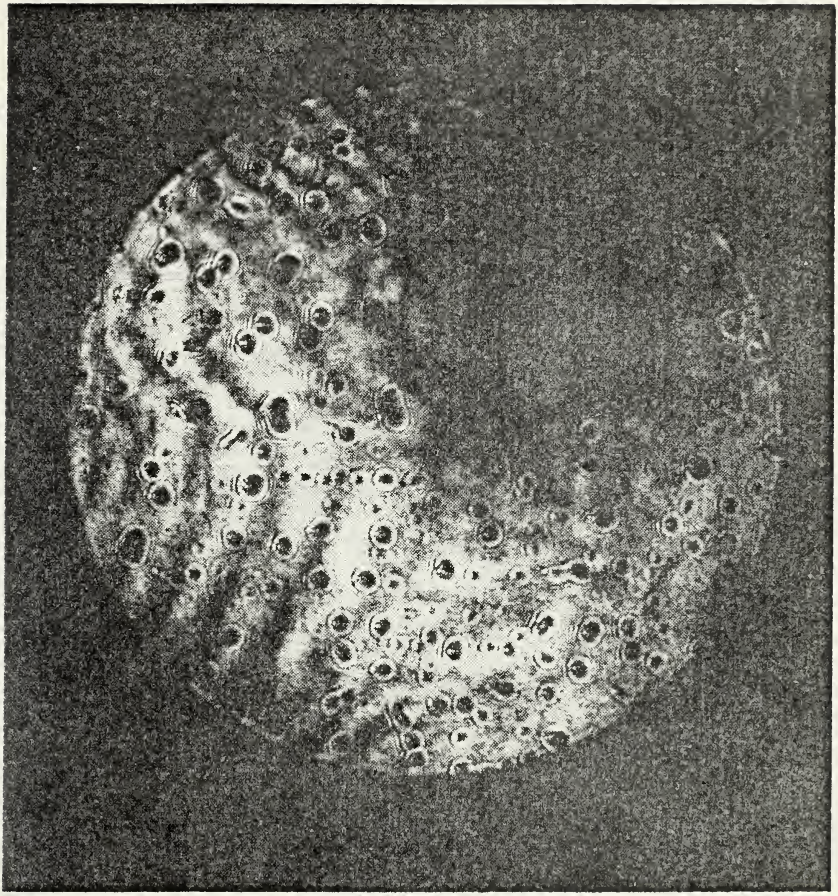


Figure 16. Compression Waves

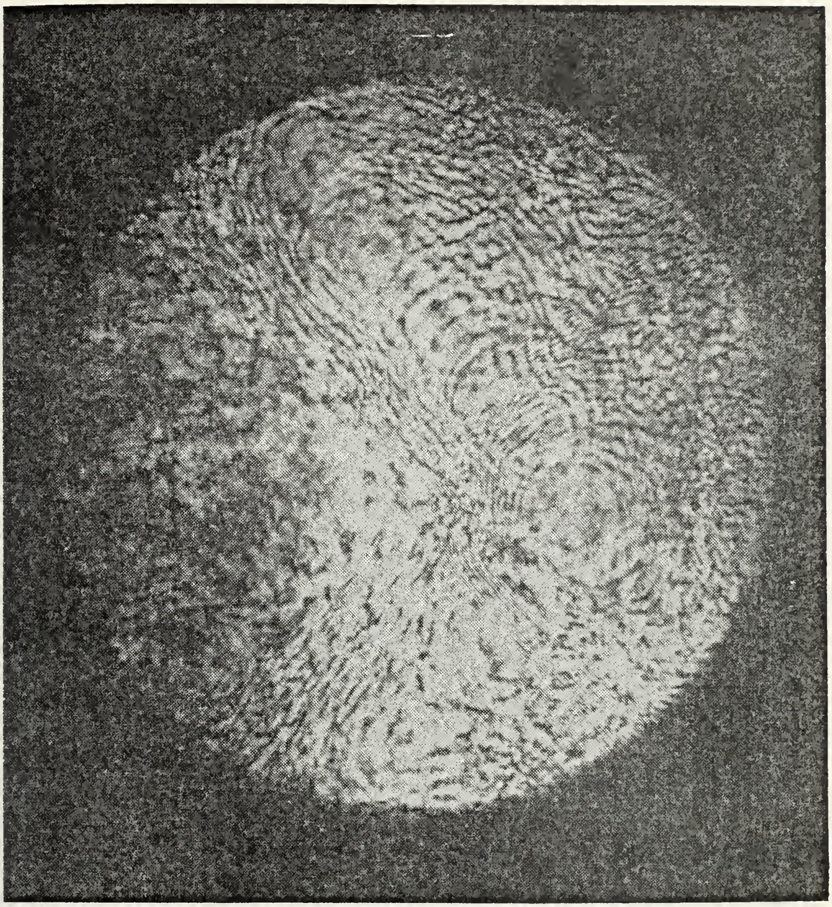


Figure 17. Bow Wave

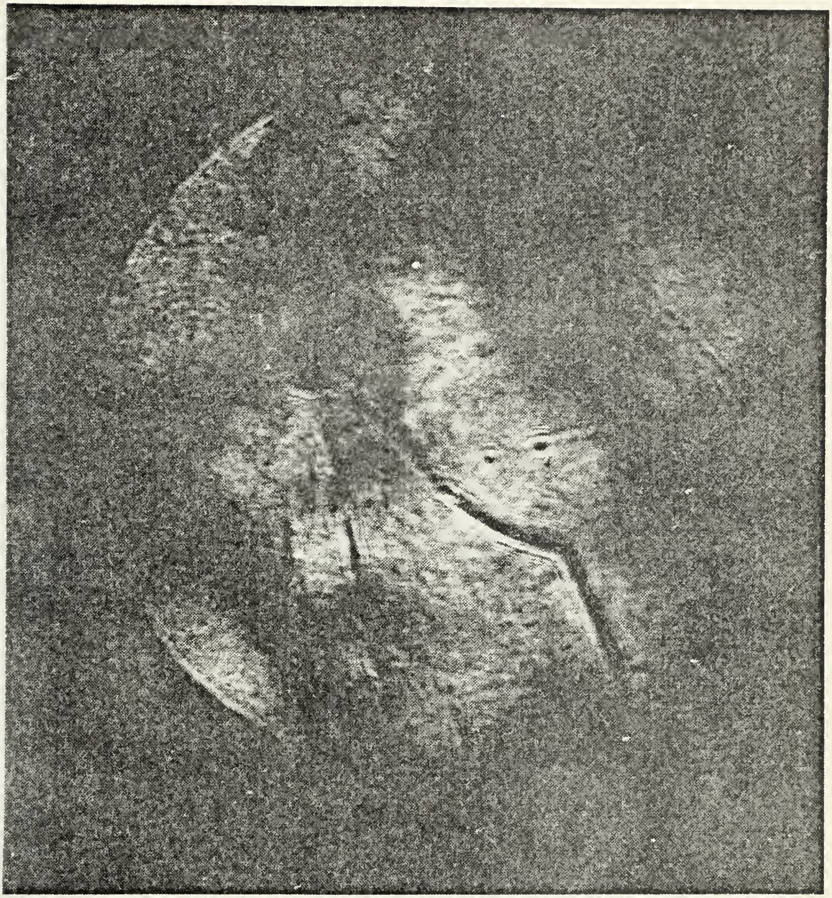


Figure 18. Hologram Showing Carbon Deposits

GUN BARREL PROJECT

Demensions: 6 Regions, 6 Zones

Regions	Zones	Length (cm)	Area (cmsq)	Volume (cc)
1	1	1.47	2.95	4.35
2	1	1.47	2.95	4.35
3	1	1.47	2.95	4.35
4	1	1.47	2.95	4.35
5	1	1.47	2.95	4.35
6	1	5.40	2.95	15.93

INITIAL CONDITIONS

Powder Conditions: Grams Powder = 38.23
TBURND = 1.00 Millisec

Materials:

Region	NEQST	Pressure (psi)	Temp. (Deg. K)	Molec. Wt. (gm/mole)
1	2	14.7	300.0	125.00
2	2	14.7	300.0	125.00
3	2	14.7	300.0	125.00
4	2	14.7	300.0	125.00
5	2	14.7	300.0	125.00
6	3	3.0	300.0	55.85

Print out every 0.20 millisec up to 10.00 millisec

Print out every 0.050 millisec up to break

Print out every 0.200 millisec up to launch

Mass of Projectile = 90.0 gm

Break Valve Strength = 690.0 Bars

Number of Pressure Points: 1

Location of Pressure Points: 14.0 cm

Figure 19. Computer Output Format

GUN BARREL PROJECT

Cycle 290	T(Millisec)	1.88443E00
	DT(Millisec)	2.18257E-02

j	X(CM)	VELOCITY (CM/MS)	PRESSURE (BARS)
1	0.0	0.0	1.01381E 03
2	1.46490E 02	1.01004E 02	8.52849E 02
3	1.47602E 02	1.03653E 02	7.78181E 02
4	1.48734E 02	1.06449E 02	8.85098E 02
5	1.49668E 02	1.07232E 02	1.05442E 03
6	1.50551E 02	1.06399E 02	3.98267E 02

Figure 20. Computer Output Format

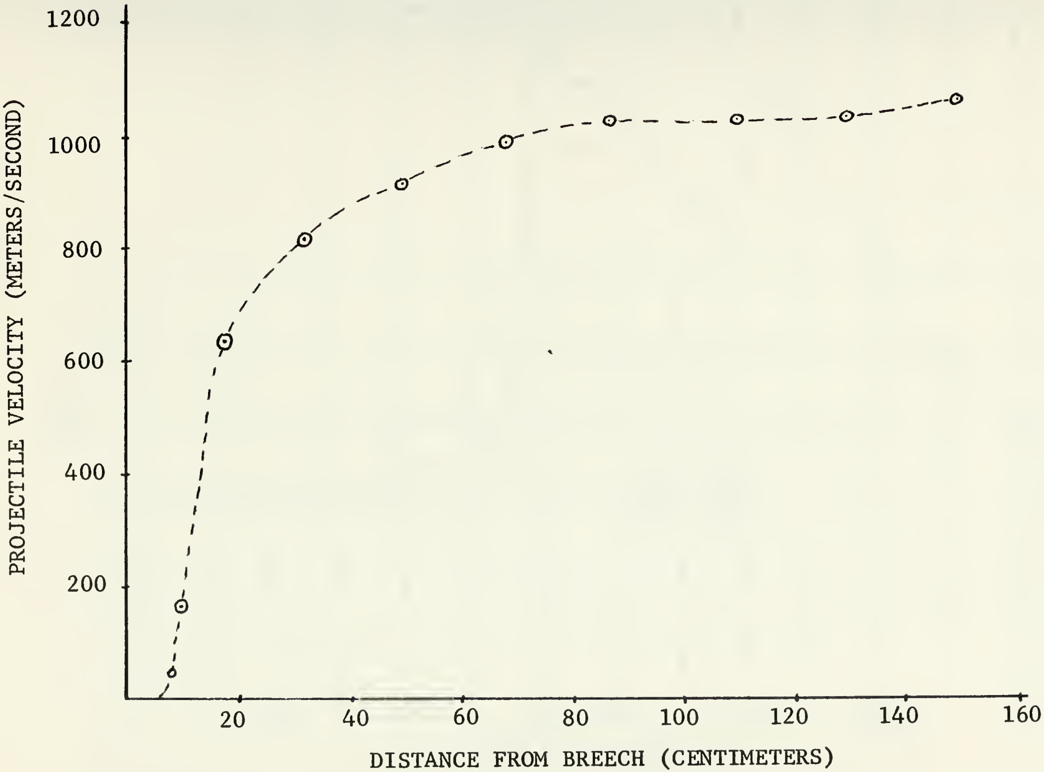


Figure 21. Projectile Velocity vs. Position

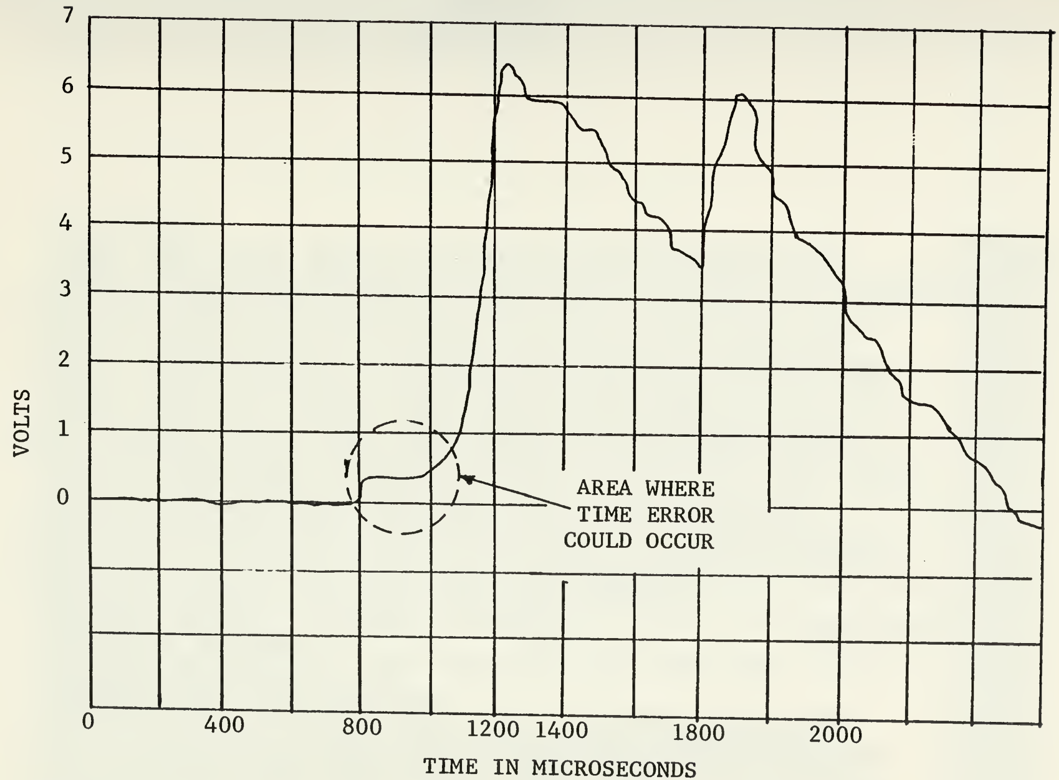


Figure 22. Pressure Trace Output from Pressure Transducer Locate 2.5 inches Aft of Observation Port

APPENDIX A

GUN PROJECT

```
C      MAIN PROGRAM                                                         GUNN0001
       CCMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL           GUNN0002
       CCMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN0003
      1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNN0004
      2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,    GUNN0005
      3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,      GUNN0006
      4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,          GUNN0007
      5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,      GUNN0008
      6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,     GUNN0009
      7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP        GUNN0010
       COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,     GUNN0011
      1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,     GUNN0012
      2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,        GUNN0013
      3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR     GUNN0014
       DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN0015
      1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN0016
      2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),           GUNN0017
      3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN0018
      4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),     GUNN0019
      5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),     GUNN0020
      6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN0021
      7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                      GUNN0022
       DIMENSION XP1(500), XP2(500), PP1(500), VP2(500),XP3(500),PP3(500)GUNN0023
       DIMENSION XPO(10), ISTOPX(10), NPTPL(10),                 TPOX(500),GUNN0024
      1PPLT(500), TPLT(500)                                                 GUNN0025
       DIMENSION ISTORM(100), STORM(100),AVEL(100),ALOAD(100),AGAS(100)    GUNN0026
       DIMENSIONXP4(500),PP4(500)                                           GUNN0027
       DIMENSICN DATA(150),PRSTAB(90)                                       GUNN0028
       DIMENSICN PMDMAX(200), TMDMAX(200), PMDMIN(200), TMDMIN(200)         GUNN0029
       NAMELIST/READ1/AMOL,AREA1,AREA2,AREA3,CALPGM,CQSQX4,EMLEAD,          GUNN0030
      1EMPIST,EMPROJ,FRAC,GAMMA,GASPRS,GMSPDR,HYDRD1,HYDRD2,IHEL,IMAX,      GUNN0031
      2INU,IPOX,JPROJ,NCHEKE,NDATE1,NDATE2,NDATE3,NEQST,NPOX,NUMBER,        GUNN0032
      3NZONES,OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PCON3,PO,PVERR,PVWANT,       GUNN0033
      4R,RADIUS,SHPR,SLOPE,TBURND,TMAX1,TMAX2,TO,UZERO,XPO,XPV1,XPV2,       GUNN0034
      5XSTOP                                                                GUNN0035
C      INITIAL CONDITIONS FOR PROGRAM                                       GUNN0036
```

```
      T=0.0                                                             GUNN0037
      ICATA=0                                                           GUNN0038
  123 NI =0                                                             GUNN0039
      M=6                                                               GUNN0040
      CATA NREAD,NPRINT/5,6/                                            GUNN0041
      NPVITR=1                                                          GUNN0042
    1 CALL ZEOAB                                                        GUNN0043
      CALL ZEROA(500,XP1,XP2,PP1,VP2,XP3)                               GUNN0044
      CALL ZEROA(500,PP3,PP1,PP1,PP1,PP1)                               GUNN0045
      CALL ZEROA(10,ISTOPX,ISTOPX,ISTOPX,ISTOPX,ISTOPX)                 GUNN0046
      INTERJ(31)=M                                                      GUNN0047
      CPMAX=0.0                                                         GUNN0048
      PTMAX=0.0                                                         GUNN0049
      AMFMAX=0.0                                                        GUNN0050
      NTIMPT=0                                                          GUNN0051
      IP=0                                                              GUNN0052
      NPUNCH=1                                                          GUNN0053
      IPNCHX=0                                                          GUNN0054
      LN = 0                                                            GUNN0055
      IPV1 = 1                                                          GUNN0056
      IPV2 = 2                                                          GUNN0057
C     ENC INITIAL CONDITIONS FOR PROGRAM, BEGIN INPUT FOR RUN,NEW OR ITEGUNN0058
      IF(NPVITR.EQ.1)GO TO 41                                           GUNN0059
      NPVITR = 1                                                        GUNN0060
C     INPUT FOR ITERATION FROM STORAGE                                  GUNN0061
  620 CALL STORE (ISTORM, STORM)                                        GUNN0062
      EMLEAD=STORM(97)                                                  GUNN0063
      HYCRD1 = STORM(98)                                                GUNN0064
      HYDRD2 = STORM(99)                                                GUNN0065
      NEQST(30) = ISTORM (100)                                          GUNN0066
      IF(IDATA)8,8,608                                                  GUNN0067
   41 CONTINUE                                                          GUNN0068
C     INPUT FOR NEW RUN, STORAGE OF INPUT                               GUNN0069
      READ(NREAD,604)IDATA,IPRNTZ,ITRNSF,IPUNCH,DTSQ(199)               GUNN0070
  604 FCRMAT(4I3,F10.0)                                                 GUNN0071
      IF(ITRNSF.EQ.0) GO TO 619                                         GUNN0072
      M=6                                                               GUNN0073
      INTERJ(31)=M                                                      GUNN0074
  619 IF(IDATA)606,606,620                                              GUNN0075
  608 READ(NREAD,READ1)                                                 GUNN0076
      ICATA=0                                                           GUNN0077
      GO TO 610                                                         GUNN0078
  606 CALL READ                                                         GUNN0079
      READ(NREAD,20) IPOX, NPOX,(XPO(M), M=1, NPOX)                     GUNN0080
      REAC(NREAD, 49) XPV1, XPV2, PVERR, PVWANT                         GUNN0081
      REAC(NREAD,6)R,EMPIST, FRAC, EMLEAD                               GUNN0082
    6 FORMAT(E10.4,3F10.0)                                              GUNN0083
      READ (NREAD,49) (AMOL(I),I=1,IMAX)                                GUNN0086
```

```
      READ (NREAD,49) (TO(I),I=1,IMAX)                                  GUNN0085
      READ (NREAD,49) (PO(I),I=1,IMAX)                                  GUNN0084
   49 FORMAT(7F10.0)                                                    GUNN0087
  610 CONTINUE                                                          GUNN0088
      CALL STORIN (ISTORM, STORM)                                       GUNN0089
      STORM(97)=EMLEAD                                                  GUNN0090
      STORM(98)=HYDRD1                                                  GUNN0091
      STORM(99)=HYDRD2                                                  GUNN0092
      ISTORM(100) = IPOX                                                GUNN0093
C     INITIAL CONDIYIONS AND CONSTANTS FOR RUN                          GUNN0094
    8 NPTN=NZONES(1)+NZONES(2)+NZONES(3)+1                              GUNN0095
      XSST=FRAC*OUTBDY(5)                                               GUNN0096
      NEQST(30) = IPOX                                                  GUNN0097
  616 CALL CALCUL (EMLEAD)                                              GUNN0098
      IF(NI.NE.0)GO TO 603                                              GUNN0099
      CALL PRINTO(EMLEAD,FRAC,XPV1,XPV2,PVWANT,NPOX,IPOX,XPO)           GUNN0100
      IF(IPRNTZ.EQ.0)GO TO 603                                          GUNN0101
      READ(NREAD,11)ILASTK                                              GUNN0102
      IF(ILASTK)123,12,1                                                GUNN0103
  603 CALL SETUP                                                        GUNN0104
      DO 706 IMP=1, JLAST                                               GUNN0105
      PMDMIN(IMP)=PPLUSQ(IMP)                                           GUNN0106
  706 PMDMAX(IMP)=PPLUSQ(IMP)                                           GUNN0107
C     MAIN LOOP OF PROGRAM - DYNMEQ, LFTOVER, AND OUTPUT                GUNN0108
    2 CALL DYNMEQ                                                       GUNN0109
      CALL LFTOVR(IPNCHX)                                               GUNN0110
      DO 710 IMP=1, JLAST                                               GUNN0111
      IF(PPLUSQ(IMP).GT.PMDMIN(IMP))  GO TO 705                         GUNN0112
      PMDMIN(IMP)=PPLUSQ(IMP)                                           GUNN0113
      TMDMIN(IMP)=T                                                     GUNN0114
  705 IF(PPLUSQ(IMP).LT.PMDMAX(IMP))   GO TO 710                        GUNN0115
      PMDMAX(IMP)=PPLUSQ(IMP)                                           GUNN0116
      TMDMAX(IMP)=T                                                     GUNN0117
  710 CONTINUE                                                          GUNN0118
      IF(IPUNCH.EQ.0.OR.JPROJ.NE.300) GO TO 627                         GUNN0119
      PRSTAB(NPUNCH)=T-DTSQ(200)                                        GUNN0120
      NPNP1=NPUNCH+1                                                    GUNN0121
      JPLHAF=INTERJ(6)                                                  GUNN0122
      J=JPLHAF                                                          GUNN0123
      JMNHAF=JPLHAF-1                                                   GUNN0124
      DUD1=26./18.*PPLUSQ(JMNHAF)-1./9.*PPLUSQ(JMNHAF-1)                GUNN0125
  707 PRSTAB(NPNP1)=DUD1                                                GUNN0126
      IF(T.GT.(DTSQ(200)+DTSQ(199))) GO TO 647                          GUNN0127
      PRSTAB(NPNP1)=PRSTAB(NPNP1)*(T-DTSQ(200))/DTSQ(199)               GUNN0128
  647 NPUNCH=NPUNCH+2                                                   GUNN0129
      IF(91-NPUNCH)625,625,627                                          GUNN0130
  625 PUNCH 641, PRSTAB                                                 GUNN0131
  641 FORMAT(3(F12.8,E12.8))                                            GUNN0132
```

```
      NPUNCH=1                                                          GUNN0133
  627 CONTINUE                                                          GUNN0134
  630 M=6                                                               GUNN0135
   72 CONTINUE                                                          GUNN0136
C     STORAGE OF MAXIMUM PRESSURES                                      GUNN0137
      INER51 = INTERJ(6) -1                                             GUNN0138
      CPMAX=AMAX1(CPMAX,PPLUSQ(NPTN))                                   GUNN0139
      PTMAX=AMAX1(PTMAX, PPLUSQ(NPTN-1),PPLUSQ(NPTN-2),PPLUSQ(NPTN-3))  GUNN0140
      AMPMAX=AMAX1(AMPMAX,PPLUSQ(INER51))                               GUNN0141
C     DETERMINATION IF MODEL HAS BEEN LAUNCHED                          GUNN0142
      IF(XSTOP-X(JLAST,NPLUS1)) 9, 3,3                                  GUNN0143
C     ROUTINE STORAGE OF POINTS TO BE PLOTTED                           GUNN0144
    3 IF(IPOX.EQ.5)  GO TO 2                                            GUNN0145
      IF ( X(NPTN, N) . LT . XSST )  GO TO 2                            GUNN0146
      KN=NCYCLE/6                                                       GUNN0147
      QN = KN                                                           GUNN0148
      SN=NCYCLE                                                         GUNN0149
      TN=SN/6.                                                          GUNN0150
      IF(TN-QN) 4, 4, 2                                                 GUNN0151
    4 IF(LN.GT.498) GO TO 7                                             GUNN0152
      LN = LN+ 1                                                        GUNN0153
      IF (IPOX.EQ.6) GO TO 75                                           GUNN0154
      XP3(LN)=T                                                         GUNN0155
      PP3(LN)=PPLUSQ(NPTN)                                              GUNN0156
      XP4(LN)=X(NPTN-1,N)                                               GUNN0157
      PP4(LN)=PPLUSQ(NPTN-1)                                            GUNN0158
      IF(IPOX.EQ.1) GO TO 51                                            GUNN0159
      DO 60  INPOX=1, NPOX                                              GUNN0160
      IF(ISTOPX(INPOX).GE.1) GO TO 60                                   GUNN0161
      NTIMPT=LN                                                         GUNN0162
      DO 58 INPTN=2,JLAST1                                              GUNN0163
      IF(XPO(INPOX).LT.X1(INPTN)) GO TO 59                              GUNN0164
   58 CONTINUE                                                          GUNN0165
      DUMVAR(LN,INPOX)=PPLUSQ(INER51)                                   GUNN0166
      NPTPL(INPOX)=LN                                                   GUNN0167
      GO TO 60                                                          GUNN0168
   59 DUMVAR(LN,INPOX)=PPLUSQ(INPTN-1)+(PPLUSQ(INPTN-1)-PPLUSQ(INPTN))  GUNN0169
     1/(X1(INPTN-1)-X1(INPTN))*(XPO(INPOX)-X1(INPTN-1))                 GUNN0170
      NPTPL(INPOX)=LN                                                   GUNN0171
      IF(LN.EQ.1099)GO TO 55                                            GUNN0172
      GO TO 60                                                          GUNN0173
   55 ISTOPX(INPOX)=2                                                   GUNN0174
      NPTPL(INPOX)=LN                                                   GUNN0175
   60 CONTINUE                                                          GUNN0176
      IF (IPOX.NE.6) GO TO 78                                           GUNN0177
   75 DUMVAR(LN,1) =PPLUSQ(INER51)                                      GUNN0178
   78 TPOX(LN)=T                                                        GUNN0179
      IF (IPOX.EQ.6) GO TO 2                                            GUNN0180
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   51 IF(IPOX.EQ.2) GO TO 52                                            GUNN0181
C     PROGRAM TO FIND MAX IN REGION TO GO HERE                          GUNN0182
   52 CONTINUE                                                          GUNN0183
C     STORAGE OF MODEL PLOTS AFTER BREAK VALVE                          GUNN0184
    7 IF(JPROJ-300) 13,5,13                                             GUNN0185
    5 IF(IP.GT.498) GO TO 2                                             GUNN0186
      IP=IP+1                                                           GUNN0187
      IF(XSTOP.EQ.3000.) GO TO 76                                       GUNN0188
   10 XP1(IP)=X(JLAST,N)                                                GUNN0189
      XP2(IP)=X(JLAST,N)                                                GUNN0190
      PP1(IP)=PPLUSQ(INER51)                                            GUNN0191
      VP2(IP)=U(JLAST, NMNHAF)                                          GUNN0192
   13 GO TO 2                                                           GUNN0193
C     PCINT OF RETURN TO MAIN LOOP OF PROGRAM                           GUNN0194
C     FINAL STORAGE OF POINTS TO BE PLOTTED, AND WRITING OF ALL PLOT TAPGUNN0195
    9 IF (IPOX.EQ.5) GO TO  25                                          GUNN0196
      IF (IPOX.EQ.6) GO TO 76                                           GUNN0197
      IP=IP+1                                                           GUNN0198
      XP1(IP)=X(JLAST,N)                                                GUNN0199
      XP2(IP)=X(JLAST,N)                                                GUNN0200
      PP1(IP)=PPLUSQ(INER51)                                            GUNN0201
      VP2(IP)=U(JLAST,NMNHAF)                                           GUNN0202
      GO TO 36                                                          GUNN0203
   35 NPOX=1                                                            GUNN0204
   36 DO 70 IPLTXT=1,NPOX                                               GUNN0205
      NPTTX=NPTPL(IPLTXT)                                               GUNN0206
      IF(NPTTX.LT.10) GO TO 70                                          GUNN0207
      NPTTT=NPTPL(IPLTXT)                                               GUNN0208
      DO 80 ITXP=1,NPTTT                                                GUNN0209
      TPLT(ITXP)=TPOX(ITXP)                                             GUNN0210
   80 PPLT(ITXP)=DUMVAR(ITXP, IPLTXT)                                   GUNN0211
      IF(JPROJ.NE.300) GO TO 1                                          GUNN0212
   70 CONTINUE                                                          GUNN0213
      GO TO 25                                                          GUNN0214
   76 DO 93 ITXP=1, LN                                                  GUNN0215
   93 PPLT(ITXP) = DUMVAR (ITXP,1)                                      GUNN0216
C     TERMINATION OF RUN, RETURN FOR NEW INPUT                          GUNN0217
   25 READ(NREAD,11) ILASTK                                             GUNN0218
      IF((IPUNCH.EQ.0).OR.(NPUNCH.EQ.1))  GO TO 629                     GUNN0219
      NPUNCH=NPUNCH-1                                                   GUNN0220
      PUNCH 641, (PRSTAB(IPXX), IPXX=1,NPUNCH)                          GUNN0221
  629 CONTINUE                                                          GUNN0222
      WRITE(6, 45) CPMAX, PTMAX, AMPMAX                                 GUNN0223
      WRITE(6,704) ((IT,PMDMIN(IT),TMDMIN(IT),PMDMAX(IT),TMDMAX(IT)     GUNN0224
     1,IT=1,JLAST))                                                     GUNN0225
  704 FORMAT(I3,2X,E12.6,2X,E12.6,2X,E12.6,2X,E12.6)                    GUNN0226
   45 FORMAT(3F20.2)                                                    GUNN0227
      IF(ILASTK) 15, 12, 1                                              GUNN0228
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15 WRITE(6,44)(NI,((AVEL(I),ALOAD(I),AGAS(I)),I=1,NI))                   GUNNO229
   GO TO 123                                                            GUNNO230
12 STOP                                                                 GUNNO231
20 FORMAT (2I2,7F10.0)                                                  GUNNO232
44 FORMAT(I3/(3F10.0))                                                  GUNNO233
11 FORMAT(I3)                                                           GUNNO234
   END                                                                  GUNNO235
   SUBROUTINE READ                                                      GUNNO236
C     READ DIMENSIONS,INITIAL CONDITIONS,AND POWDER PARAMETERS          GUNNO237
   COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL           GUNNO238
   COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNNO239
  1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNNO240
  2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  GUNNO241
  3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GUNNO242
  4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,         GUNNO243
  5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,     GUNNO244
  6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   GUNNO245
  7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      GUNNO246
   COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   GUNNO247
  1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   GUNNO248
  2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      GUNNO249
  3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GUNNO250
   DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNNO251
  1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNNO252
  2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         GUNNO253
  3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNNO254
  4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   GUNNO255
  5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   GUNNO256
  6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNNO257
  7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    GUNNO258
 1 FORMAT(20I3)                                                         GUNNO259
   DATA NREAD/5/                                                        GUNNO260
 2 FORMAT(F10.0,I5)                                                     GUNNO261
 3 FORMAT(7F10.0)                                                       GUNNO262
   READ(NREAD,1) IMAX,NDATE1,NDATE2,NDATE3,NUMBER,NCHEKE,INU,JPROJ      GUNNO263
   READ(NREAD,1) (NEQST(I),I=1,IMAX)                                    GUNNO264
   READ(NREAD,1) (NZONES(I),I=1,IMAX)                                   GUNNO265
   READ(NREAD,3) (OUTBDY(I),I=1,IMAX)                                   GUNNO266
   READ(NREAD,3) (GAMMA(I),I=1,IMAX)                                    GUNNO267
   READ(NREAD,3) (CQSQX4(I),I=1,IMAX)                                   GUNNO268
   READ(NREAD,3) AREA1,AREA2,AREA3,PCON1,PCON2,SHPR,EMPROJ              GUNNO269
   READ(NREAD,3) OUTDT1,TMAX1,OUTDT2,TMAX2,XSTOP                        GUNNO270
 8 IF(INU) 9,901,9                                                      GUNNO271
 9 READ(NREAD,3) (UZERO(I),I=1,IMAX)                                    GUNNO272
   GO TO 904                                                            GUNNO273
901 DO 902 I=1,IMAX                                                     GUNNO274
902 UZERO(I)=0.                                                         GUNNO275
904 READ(NREAD,100)PCON3,SLOPE,RADIUS                                   GUNNO276
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      READ(NREAD,5)CALPGM,TBURND,GMSPDR,GASPRS,IHEL                     GUNNO277
      READ(NREAD,123) HYDRD1,HYDRD2                                     GUNNO278
  123 FORMAT(2E15.5)                                                    GUNNO279
      WRITE(6,123)HYDRD1,HYDRD2                                         GUNNO280
    5 FORMAT(4F10.0,I4)                                                 GUNNO281
  100 FORMAT(7F10.0)                                                    GUNNO282
  903 RETURN                                                            GUNNO283
      END                                                               GUNNO284
      SUBROUTINE PRINTO(EMLEAD,FRAC,XPV1,XPV2,PVWANT,NPOX,IPOX,XPO)     GUNNO285
C     PRINT DIMENSIONS AND POWDER CONDITIONS                            GUNNO286
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        GUNNO287
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNNO288
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNNO289
     2DPDMU,CQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, GUNNO290
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,   GUNNO291
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERC,SHPR,       GUNNO292
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   GUNNO293
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  GUNNO294
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNNO295
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GUNNO296
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  GUNNO297
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     GUNNO298
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  GUNNO299
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNNO300
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNNO301
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNNO302
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNNO303
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  GUNNO304
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNNO305
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNNO306
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNNO307
      DIMENSION XLGTH(30),ZQMASS(30),XPO(10),REGVOL(30)                 GUNNO308
      WRITE(6,65)                                                       GUNNO309
   65 FORMAT(1H1)                                                       GUNNO310
      XLGTH(1)=OUTBDY(1)                                                GUNNO311
      REGVOL(1)=AREA1*XLGTH(1)                                          GUNNO312
      IF(IMAX.EQ.1) GO TO 210                                           GUNNO313
      DO 200 KQX=2,IMAX                                                 GUNNO314
  200 XLGTH(KQX)=OUTBDY(KQX)-OUTBDY(KQX-1)                              GUNNO315
      KQXX=IMAX-1                                                       GUNNO316
      DO 201 KQX=2,KQXX                                                 GUNNO317
  201 REGVOL(KQX)=AREA2*XLGTH(KQX)                                      GUNNO318
      REGVOL(IMAX)=AREA3*XLGTH(IMAX)                                    GUNNO319
  210 ANGLE=ATAN(SLOPE)                                                 GUNNO320
      ANGLE=ANGLE*(360./6.2832)                                         GUNNO321
      WRITE (6,100) NUMBER,NDATE1,NDATE2,NDATE3                         GUNNO322
      WRITE (6,102) IMAX,JPROJ                                          GUNNO323
      I=1                                                               GUNNO324
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      WRITE (6,103) I,NZONES(I),XLGTH(I),AREA1,REGVOL(I)                GUNN0325
      IF(IMAX.EQ.1) GO TO 211                                           GUNN0326
      KQX=IMAX-1                                                        GUNN0327
      WRITE (6,103) (I,NZONES(I),XLGTH(I),AREA2,REGVOL(I),I=2,KQX)      GUNN0328
      WRITE (6,103) IMAX,NZONES(IMAX),XLGTH(IMAX),AREA3,REGVOL(IMAX)    GUNN0329
  211 WRITE (6,105) SLOPE,ANGLE                                         GUNN0330
      WRITE (6,111) CALPGM,TBURND,GMSPDR,GASPRS                         GUNN0331
      WRITE (6,106)                                                     GUNN0332
      WRITE (6,108) (I,NEQST(I),PO(I),TO(I),AMOL(I),CQSQX4(I),I=1,IMAX) GUNN0333
      WRITE (6,109)                                                     GUNN0334
      WRITE (6,110) (I,GAMMA(I),EZERO(I),ROZERO(I),VZERO(I),I=1,IMAX)   GUNN0335
      WRITE (6,124) R                                                   GUNN0336
      WRITE (6,114) XPV1,XPV2,PVWANT                                    GUNN0337
      WRITE (6,115) OUTDT1,TMAX1,OUTDT2,TMAX2                           GUNN0338
      EMLEAX=EMLEAD*453.59                                              GUNN0339
      EMPISX=EMPIST*453.59                                              GUNN0340
      XXMAS=REGVOL(IMAX)*ROZERO(IMAX)                                   GUNN0341
      SHPRX=SHPR*14.504                                                 GUNN0342
      WRITE(6,112) EMLEAD,EMLEAX,EMPIST,EMPISX,XXMAS                    GUNN0343
      WRITE (6,113) SHPR,SHPRX                                          GUNN0344
      KQX=IPOX+1                                                        GUNN0345
      GO TO (10,11,12,12,12,13,14),KQX                                  GUNN0346
   10 WRITE (6,119) IPOX                                                GUNN0347
      GO TO 15                                                          GUNN0348
   11 WRITE (6,120) IPOX                                                GUNN0349
      GO TO 15                                                          GUNN0350
   12 WRITE (6,123) IPOX                                                GUNN0351
      GO TO 15                                                          GUNN0352
   13 WRITE (6,121) IPOX                                                GUNN0353
      GO TO 15                                                          GUNN0354
   14 WRITE (6,122) IPOX                                                GUNN0355
   15 WRITE (6,116) NPOX                                                GUNN0356
      WRITE (6,117) (XPO(I),I=1,NPOX)                                   GUNN0357
      WRITE (6,118) FRAC                                                GUNN0358
      WRITE(6,65)                                                       GUNN0359
      RETURN                                                            GUNN0360
  100 FORMAT(23X,36HHYPERVELOCITY MODEL LAUNCHER PROGRAM//22X,19HCOMPUTEGUNN0361
     1R RUN NUMBER,I5,7H  DATE ,I2,1H/,I2,1H/,I2)                       GUNN0362
  102 FORMAT(1H /34X,14HGUN DIMENSIONS/31X,I2,10H REGIONS  , I3,6H ZONESGUNN0363
     1//12X,6HREGION,5X,5HZONES,6X,6HLENGTH,9X,4HAREA,11X,6HVOLUME/35X,4GUNN0364
     2H(CM), 9X,6H(CMSQ),11X,4H(CC)/1H )                                GUNN0365
  103 FORMAT(14X,I2,9X,I2,2X,F10.2,5X,F10.2,7X,F10.2)                   GUNN0366
  104 FORMAT(14X,I2,9X,I2,2X,F10.2,11X,3H---,12X,3H---)                 GUNN0367
  105 FORMAT(1H /19X,7HSLOPE =,F8.4,9X,7HANGLE =,F6.2,5H  DEG)          GUNN0368
  106 FORMAT(1H /5X,12HMATERIALS --//7X,6HREGION,5X,5HNEQST,5X,8HPRESSURGUNN0369
     1E,7X,4HTEMP,9X,8HMOLEC WT,6X,6HCQSQX4/30X,5H(PSI),6X,7H(DEG K),7X,GUNN0370
     29H(GM/MOLE)/1H )                                                  GUNN0371
  108 FORMAT(9X,I2,8X,I2,5X,F9.2,6X,F7.2,6X,F9.4,6X,F5.1)               GUNN0372
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109 FORMAT(1H /6X,6HREGION,4X,5HGAMMA,9X,6HENERGY,10X,7HDENSITY,9X,9HSGUNN0373
   1P VOLUME/26X,13H(BARS-CC/CCO),7X,7H(GM/CC),9X,8H(CC/CCO)/1H )      GUNN0374
110 FORMAT(8X,I2,5X,  F6.3,6X,  E11.4,6X,E11.4,6X,E11.4)               GUNN0375
111 FORMAT(1H //32X,18HINITIAL CONDITIONS/5X,20HPOWDER CONDITIONS --//GUNN0376
   114X,8HCALPGM =,F12.4,6X,8HTBURND =,F12.4,6H  MSEC/14X,8HGMSPDR =,FGUNN0377
   212.4,6X,8HGASPRS =,F12.4,5H  PSI)                                   GUNN0378
112 FORMAT(1H /5X,10HWEIGHTS --//9X,6HPISTON/13X,23HMASS OF FIRST SECTGUNN0379
   1ICN =,F13.4,4H  LB,8X,1H=,F13.4,4H  GM/13X,24HMASS OF SECOND SECTIGUNN0380
   2ON =,F12.4,4H  LB,8X,1H=,F13.4,4H  GM//9X,5HMODEL/13X,15HMASS OF MGUNN0381
   3ODEL =,F12.4,4H  GM)                                                GUNN0382
113 FORMAT(1H /18X,22HBREAK VALVE STRENGTH =,F10.2,6H  BARS,5X,1H=,F10GUNN0383
   1.2,5H  PSI)                                                         GUNN0384
114 FORMAT(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H  CM   ,GUNN0385
   110X,6HXPV2 =,F10.2,7H  CM   /10X,18HDESIRED VELOCITY =,F10.2,7H FTGUNN0386
   2/SEC)                                                               GUNN0387
115 FORMAT(2H  //20X,15HPRINT OUT EVERY,F7.3,11H MSEC UP TO,F7.3,5H MSGUNN0388
   1EC/20X,15HPRINT OUT EVERY,F7.3,17H MSEC UP TO BREAK/20X,15HPRINT OGUNN0389
   2UT EVERY,F7.3,18H MSEC UP TO LAUNCH)                                GUNN0390
116 FORMAT(1H /10X,26HNUMBER OF PRESSURE POINTS ,I4//10X,27HLOCATION OGUNN0391
   1F PRESSURE POINTS)                                                  GUNN0392
117 FORMAT(20X,F9.2,3H CM)                                              GUNN0393
118 FORMAT(1H /10X,20HPLOT START FRACTION ,1PE11.4)                     GUNN0394
119 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3,34H  (ALL PLOTS, ALL PREGUNN0395
   1SSURE POINTS))                                                      GUNN0396
120 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3,33H  (ALL PLOTS, NO PRESGUNN0397
   1SURE POINTS))                                                       GUNN0398
121 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3,12H  (NO PLOTS))          GUNN0399
122 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3,24H  (ONLY PRESSURE POINGUNN0400
   1TS))                                                                GUNN0401
123 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3)                          GUNN0402
124 FORMAT(1H /6X,3HR =,1PE11.4)                                        GUNN0403
    RETURN                                                              GUNN0404
    END                                                                 GUNN0405
    SUBROUTINE SETUP                                                    GUNN0406
C   SETS INITIAL CONDITIONS FOR CYCLE 0                                 GUNN0407
    COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL          GUNN0408
    COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN0409
   1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,CMU,DPDE,GUNN0410
   2DPCMU,CQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  GUNN0411
   3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GUNN0412
   4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,C,ROZERC,SHPR,        GUNN0413
   5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    GUNN0414
   6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   GUNN0415
   7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      GUNN0416
    COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   GUNN0417
   1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   GUNN0418
   2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      GUNN0419
   3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GUNN0420
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      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN0421
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN0422
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNN0423
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN0424
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  GUNN0425
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNN0426
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN0427
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNN0428
      N=1                                                               GUNN0429
      NMNHAF=N                                                          GUNN0430
      NPL3HF=N                                                          GUNN0431
      NPLUS1=1                                                          GUNN0432
      NPLHAF=NPLUS1                                                     GUNN0433
      NN=3                                                              GUNN0434
      NCYCLE=0                                                          GUNN0435
      T=0.                                                              GUNN0436
      DTMIN(NN)=0.                                                      GUNN0437
      TNEXT=OUTDT1                                                      GUNN0438
      TPRINT=CUTDT1                                                     GUNN0439
      TMAX=TMAX1                                                        GUNN0440
      CALL GENSUB                                                       GUNN0441
      NPLUS1=2                                                          GUNN0442
      NPLHAF=NPLUS1                                                     GUNN0443
      DTMIN(NN)=.0001                                                   GUNN0444
      DTMIN(NPLHAF)=.0001                                               GUNN0445
      TMINSQ(NPLHAF)=.00000001                                          GUNN0446
      RETURN                                                            GUNN0447
      END                                                               GUNN0448
      SUBROUTINE LFTOVR                                                 GUNN0449
C     DETERMINES DELTA T AND PRINT CYCLE                                GUNN0450
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        GUNN0451
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN0452
     1,DTMIN,CUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNN0453
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, GUNN0454
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,   GUNN0455
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERC,SHPR,       GUNN0456
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   GUNN0457
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  GUNN0458
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNN0459
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GUNN0460
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  GUNN0461
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     GUNN0462
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  GUNN0463
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN0464
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN0465
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNN0466
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN0467
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  GUNN0468
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     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNN0469
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN0470
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNN0471
      DTLAST=DTMIN(NPLHAF)                                              GUNN0472
      M=INTERJ(31)                                                      GUNN0473
      IF(SIGMAX.EQ.0.0)GO TO 240                                        GUNN0474
      SIGMIN=1./SIGMAX                                                  GUNN0475
      GO TO 244                                                         GUNN0476
  240 SIGMIN=0.0                                                        GUNN0477
  244 IF(SIGMIN-7.41*TMINSQ(NPLHAF))  270,270,250                       GUNN0478
  250 IF(DLAMAX-.079) 255,270,270                                       GUNN0479
  255 IF(SIGMIN-11.11*TMINSQ(NPLHAF))  265,260,260                      GUNN0480
  260 IF(DLAMAX-.065) 270,270,265                                       GUNN0481
  265 TMINSQ(NPL3HF)=TMINSQ(NPLHAF)                                     GUNN0482
      GO TO 285                                                         GUNN0483
  270 IF(DLAMAX-.01) 275,275,280                                        GUNN0484
  275 TMINSQ(NPL3HF)=SIGMIN/2.25                                        GUNN0485
      GO TO 285                                                         GUNN0486
  280 TMINSQ(NPL3HF)=AMIN1(SIGMIN/9.00,.005184*TMINSQ(NPLHAF)/DLAMAX**2)GUNN0487
  285 DTMIN(NPL3HF)=AMIN1(SQRT (TMINSQ(NPL3HF)),1.4*DTMIN(NPLHAF))      GUNN0488
  290 DTMIN(NN)=(DTMIN(NPL3HF)+DTMIN(NPLHAF))/2.                        GUNN0489
      NP=NPLUS1                                                         GUNN0490
      NPLUS1=N                                                          GUNN0491
      NPLHAF=NPLUS1                                                     GUNN0492
      N=NP                                                              GUNN0493
      NMNHAF=N                                                          GUNN0494
      NPL3HF=N                                                          GUNN0495
      EINSUM=0.                                                         GUNN0496
      ESUM=0.                                                           GUNN0497
      EKSUM=0.                                                          GUNN0498
      USQ(1)=U(1,N)**2                                                  GUNN0499
      DO 300  I=1,IMAX                                                  GUNN0500
      EINT(I)=0.                                                        GUNN0501
      EKIN(I)=0.                                                        GUNN0502
      JMAX=INTERJ(I+1)-1                                                GUNN0503
      JMIN=INTERJ(I)                                                    GUNN0504
      DO 295  J=JMIN,JMAX                                               GUNN0505
      JPLHAF=J                                                          GUNN0506
      USQ(J+1)=U(J+1,N)**2                                              GUNN0507
      X1(JPLHAF)   =(X(J,N)+X(J+1,N))/2.                                GUNN0508
      EINT(I)=EINT(I)+E(JPLHAF,N)/HALFRO(I)*HALFM(JPLHAF)               GUNN0509
  295 EKIN(I)=(USQ(J)+USQ(J+1))*HALFM(JPLHAF)    +EKIN(I)               GUNN0510
      EKIN(I)=.5*EKIN(I)                                                GUNN0511
      EINSUM=EINSUM+EINT(I)                                             GUNN0512
      EKIN(6)=.5*EMPROJ*U(JLAST,NMNHAF)**2+EKIN(6)                      GUNN0513
      EKSUM=   .5*EMPROJ*U(JLAST,NMNHAF)**2+EKSUM                       GUNN0514
  300 EKSUM=EKSUM+EKIN(I)                                               GUNN0515
      ESUM=EINSUM+EKSUM                                                 GUNN0516
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      IF(NCHEKE) 301,305,301                                            GUNNO517
  301 IF(ABS (ETOT-ESUM)-ETENTH) 305,305,302                            GUNNO518
  302 EWRONG=1.                                                         GUNNO519
      CALL OUTPUT                                                       GUNNO520
  305 IF(JPROJ-400)306,306,307                                          GUNNO521
  307 JPROJ=300                                                         GUNNO522
      TPRINT=TMAX2                                                      GUNNO523
      TNEXT=T+TPRINT                                                    GUNNO524
      CALL OUTPUT                                                       GUNNO525
      GO TO 121                                                         GUNNO526
  306 IF(TNEXT-T) 315,315,121                                           GUNNO527
  315 CALL OUTPUT                                                       GUNNO528
  316 TNEXT=TNEXT+TPRINT                                                GUNNO529
      IF(TMAX-TNEXT+.001)320,121,121                                    GUNNO530
  320 TNEXT=TNEXT-TPRINT                                                GUNNO531
      TPRINT=OUTDT2                                                     GUNNO532
      TNEXT=TNEXT+TPRINT                                                GUNNO533
      TMAX=5.*TMAX                                                      GUNNO534
  121 IF(XSTOP-X(JLAST,NPLUS1)) 556,555,555                             GUNNO535
  556 CALL OUTPUT                                                       GUNNO536
  555 RETURN                                                            GUNNO537
      END                                                               GUNNO538
      SUBROUTINE OUTPUT                                                 GUNNO539
C     PRINTS OUTPUT PARAMETERS                                          GUNNO540
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        GUNNO541
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNNO542
     1,CTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,CPDE,GUNNO543
     2DPCMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, GUNNO544
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,   GUNNO545
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERC,SHPR,       GUNNO546
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   GUNNO547
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  GUNNO548
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNNO549
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GUNNO550
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  GUNNO551
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     GUNNO552
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TC,AMOL,DUMVAR  GUNNO553
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNNO554
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNNO555
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNNO556
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNNO557
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  GUNNO558
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNNO559
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNNO560
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNNO561
      DIMENSION XP5(200), PP5(200),XP6(200),VP6(200)                    GUNNO562
      M=INTERJ(31)                                                      GUNNO563
      ILIMIT =IMAX                                                      GUNNO564
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   49 WRITE(M,1)K,NUMBER,NDATE1,NDATE2,NDATE3                              GUNN0565
   51 WRITE(M,12)                                                          GUNN0566
   52 WRITE(M,6) NCYCLE,T,DTLAST,ESUM                                      GUNN0567
      IF(NCYCLE) 53,53,400                                                 GUNN0568
   53 DO 57 JPLHAF=1,JLAST1                                                GUNN0569
   57 ZMASS(JPLHAF)=2.* HALFM(JPLHAF)                                      GUNN0570
   60 WRITE(M,2)                                                           GUNN0571
      WRITE(M,3)                                                           GUNN0572
      WRITE (M,5555)                                                       GUNN0573
      DO 604 L=1,JLAST1                                                    GUNN0574
      DO 602 IL=2,ILIMIT                                                   GUNN0575
      IF(L-INTERJ(IL) ) 602,603,602                                        GUNN0576
  602 CONTINUE                                                             GUNN0577
      WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),        GUNN0578
     1E(L,N),AREA(L,N),DTSQ(L),ZMASS(L)                                    GUNN0579
      GO TO 604                                                            GUNN0580
  603 WRITE(M,5556)                                                        GUNN0581
 5556 FORMAT(1H0)                                                          GUNN0582
      WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),        GUNN0583
     1E(L,N),AREA(L,N),DTSQ(L),ZMASS(L)                                    GUNN0584
  604 CONTINUE                                                             GUNN0585
      WRITE(M,4) JLAST,X(JLAST,N),U(JLAST,NMNHAF)                          GUNN0586
      GO TO 71                                                             GUNN0587
  400 NYDRA2=HYDRD2                                                        GUNN0588
      IF((NYDRA2.EQ.0).OR.((NYDRA2-60).EQ.0).OR.((NYDRA2-30).EQ.0))        GUNN0589
     1 GO TO 100                                                           GUNN0590
      IF((NYDRA2.GT.30).AND.(NYDRA2.LT.60))  GO TO 300                     GUNN0591
      IF(NYDRA2.GT.60) GO TO 600                                           GUNN0592
      NZN=1                                                                GUNN0593
      MZM=INTERJ(NYDRA2+1)-1                                               GUNN0594
      GO TO 200                                                            GUNN0595
  300 NYDRA2=NYDRA2-30                                                     GUNN0596
      NZN=INTERJ(NYDRA2)                                                   GUNN0597
      MZM=INTERJ(NYDRA2+1)-1                                               GUNN0598
      GO TO 200                                                            GUNN0599
  600 NYDRA2=NYDRA2-60                                                     GUNN0600
      NZN=INTERJ(NYDRA2)                                                   GUNN0601
      MZM=JLAST1                                                           GUNN0602
  200 DO 70 JK=NZN,MZM                                                     GUNN0603
      JKM=JK-NZN  + 1                                                      GUNN0604
      XP6(JKM)=X1(JK)                                                      GUNN0605
      VP6(JKM)=U(JK,NMNHAF)/100.                                           GUNN0606
      XP5(JKM)=X1(JK)                                                      GUNN0607
   70 PP5(JKM)=PPLUSQ(JK)                                                  GUNN0608
  100 CONTINUE                                                             GUNN0609
      WRITE (M,7)                                                          GUNN0610
      WRITE(M,8)                                                           GUNN0611
      WRITE (M,5555)                                                       GUNN0612
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      DO 704 L=1,JLAST1                                                  GUNN0613
      DO 702 IL=2,ILIMIT                                                 GUNN0614
      IF(L-INTERJ(IL)) 702,703,702                                       GUNN0615
  702 CONTINUE                                                           GUNN0616
      WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),      GUNN0617
     1E(L,N),AREA(L,N),DTSQ(L),X1(L)                                     GUNN0618
      GO TO 704                                                          GUNN0619
  703 WRITE(M,5555)                                                      GUNN0620
 5555 FORMAT(1H )                                                        GUNN0621
      WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),      GUNN0622
     1E(L,N),AREA(L,N),DTSQ(L),X1(L)                                     GUNN0623
  704 CONTINUE                                                           GUNN0624
      WRITE(M,4) JLAST,X(JLAST,N),U(JLAST,NMNHAF)                        GUNN0625
   71 WRITE (M,9)                                                        GUNN0626
   75 WRITE(M,10) (I,NEQST(I),EKIN(I),EINT(I),I=1,IMAX)                  GUNN0627
      WRITE(M,6) NCYCLE,T,DTLAST,ESUM                                    GUNN0628
      WRITE(M,5)                                                         GUNN0629
    5 FORMAT(1H1)                                                        GUNN0630
      IF(EWRONG) 95,95,80                                                GUNN0631
   80 WRITE(M,11)                                                        GUNN0632
   95 RETURN                                                             GUNN0633
   40 FORMAT(1I5,1P7E13.5)                                               GUNN0634
    1 FORMAT(5X, I2,20H  H V MODEL LAUNCHER,4I3)                         GUNN0635
    2 FORMAT(118H0  J     X(J,N)        U(J,N-1/2)    V(J+1/2,N)    P(J+1/2,NGUNN0636
     1) Q(J+1/2,N-1/2) E(J+1/2,N)  AREA(J,N) DTSQ(1/2,1/2)  DM(J+1/2))  GUNN0637
    3 FORMAT(114H          CM          CM/MILLISEC    CC/CCO          BARS  GUNN0638
     1       BARS       BARS-CC/CCO                MILLISECSQ   GRAMS)   GUNN0639
    4 FORMAT(I4,1P6E13.5,2E11.3,E13.5)                                   GUNN0640
    6 FORMAT(I5,1P3E15.5)                                                GUNN0641
    7 FORMAT(119H0  J     X(J,N)        U(J,N-1/2)    V(J+1/2,N)    P(J+1/2,NGUNN0642
     1) Q(J+1/2,N-1/2) E(J+1/2,N) AREA(J,N)  DTSQ(1/2,1/2)  X(J+1/2,N))  GUNN0643
    8 FORMAT(114H          CM          CM/MILLISEC    CC/CCO          BARS  GUNN0644
     1       BARS       BARS-CC/CCO                MILLISECSQ      CM )  GUNN0645
    9 FORMAT(46HOREGION  MATERIAL      K-ENERGY         I-ENERGY)        GUNN0646
   10 FORMAT(I5,I8,        2E15.5)                                       GUNN0647
   11 FORMAT(53H1                                     ENERGY CHECK)      GUNN0648
   12 FORMAT(47HOCYCLE       T                DT           TOTAL E)      GUNN0649
      END                                                                GUNN0650
      SUBROUTINE CALCUL (EMLEAD)                                         GUNN0651
C     CALCULATES INITIAL REGIONAL ENERGY,SPECIFIC VOLUME,AND DENSITY     GUNN0652
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL         GUNN0653
      COMMON AREA1,AREA2,AREA3,AREA,CQSCX4,CMAXR,CSC,CSQMAX,CP,CV,DLAMAXGUNN0654
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,CMU,DPDE,GUNN0655
     2DPCMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  GUNN0656
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GUNN0657
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERC,SHPR,        GUNN0658
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    GUNN0659
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   GUNN0660
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     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNN0661
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   GUNN0662
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   GUNN0663
     2NCATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      GUNN0664
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GUNN0665
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN0666
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN0667
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNN0668
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN0669
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   GUNN0670
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNN0671
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN0672
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNN0673
      M=INTERJ(31)                                                       GUNN0674
      DO 50 I=1, IMAX                                                    GUNN0675
      RCZERO(I)=AMOL(I)/22.4E3                                           GUNN0676
      VZERO(I)=R*TO(I)/PO(I)/AMOL(I)*14.5/1.E6*ROZERO(I)                 GUNN0677
   50 EZERO(I)=PO(I)*VZERO(I)/(GAMMA(I)-1.)/14.5                         GUNN0678
      WRITE(M,21)                                                        GUNN0679
   21 FORMAT(1H1)                                                        GUNN0680
      DO 25 IK=1,IMAX                                                    GUNN0681
      IF(PO(IK).NE.1.0) GO TO 23                                         GUNN0682
      GAMMA(IK)=1.                                                       GUNN0683
      EZERO(IK)=0.                                                       GUNN0684
      VZERO(IK)=1.0                                                      GUNN0685
      RCZERO(IK)=EMLEAD*453.7/(AREA2*(OUTBDY(2)-OUTBDY(1)))              GUNN0686
   23 IF(PO(IK).NE.2.0)  GO TO 24                                        GUNN0687
      GAMMA(IK)=1.                                                       GUNN0688
      EZERO(IK)=0.                                                       GUNN0689
      VZERO(IK)=1.0                                                      GUNN0690
      ROZERO(IK)=EMPIST*453.7/(AREA2*(OUTBDY(3)-OUTBDY(2)))              GUNN0691
   24 IF (PO(IK).NE.3.0) GO TO 25                                        GUNN0692
      GAMMA(IK)=1.                                                       GUNN0693
      EZERO(IK)=0.                                                       GUNN0694
      VZERO(IK)=1.0                                                      GUNN0695
      RCZERO(IK)=    EMPROJ/(AREA3*(OUTBDY(6)-OUTBDY(5)))                GUNN0696
      EMPROJ=0.0                                                         GUNN0697
   25 CONTINUE                                                           GUNN0698
      RETURN                                                             GUNN0699
      END                                                                GUNN0700
      SUBROUTINE ZEOAB                                                   GUNN0701
C     ZEROS ALL VARIABLES BETWEEN RUNS                                   GUNN0702
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL         GUNN0703
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN0704
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,CMU,DPDE,GUNN0705
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  GUNN0706
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GUNN0707
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERC,SHPR,        GUNN0708
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     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   GUNNO709
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  GUNNO710
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNNO711
      CCMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GUNNO712
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  GUNNO713
     2NCATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     GUNNO714
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  GUNNO715
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNNO716
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNNO717
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNNO718
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNNO719
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),C(200,2),ROZERO(30),  GUNNO720
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNNO721
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNNO722
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNNO723
      CALL ZERO(AREA1,AREA2,AREA3,CSQMAX,DLAMAX,DUDT,DTLAST,DLAST1)     GUNNO724
      CALL ZERO(DJLAST,DNZONE,DMU,DPDE,DPDMU,EINSUM,ESUM,EKSUM)         GUNNO725
      CALL ZERO(ETOT,ETENTH,EWRONG,E1,HYDRD1,HYDRD2,HYDRD3,OUTDT1)      GUNNO726
      CALL ZERO(OUTDT2,PCON1,PCON2,P1,SHPR,SIGMAX,SIGMIN,TMAX1)         GUNNO727
      CALL ZERO(TMAX2,TVDT1,TVDT2,T,TMAX,TNEXT,TPRINT,TVNEXT)           GUNNO728
      CALL ZERO(TVFREQ,TBAR,TWALL,VOLUME,XGRID,XMIN,XMAX,EMPROJ)        GUNNO729
      CALL ZERO(XSTOP,AREA1,AREA2,AREA3,CSQMAX,T,T,T)                   GUNNO730
      CALL IERO(INDEX,IMAX,INU,I,INDEX,ILIMIT,JPROJ1,JPROJ2)            GUNNO731
      CALL IERO(JMIN,JMAX,J,JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1)           GUNNO732
      CALL IERO(JMAX1,K,L,NDATE1,NDATE2,NDATE3,NUMBER,NTV)              GUNNO733
      CALL IERO(NCHEKE,NCYCLE,N,NMNHAF,NPLUS1,NPLHAF,NN,NPL3HF)         GUNNO734
      CALL IERO(NP,IQUIT,JPROJ,JSTOP,K,K,K,K)                           GUNNO735
      CALL ZEROA(30,CQSQX4,CMAXR,CP,CV,DELX)                            GUNNO736
      CALL ZEROA(200,CSQ,DLAMDA,DTSQ,DQ1,DQ2)                           GUNNO737
      CALL ZEROA(3,DTMIN,DTMIN,DTMIN,DTMIN,DTMIN)                       GUNNO738
      CALL ZEROA(30,EZERO,EINT,EKIN,GAMMA,HALFRO)                       GUNNO739
C     CALL ZEROA(30,NEQST,NZONES,OUTBDY,ROZERO,TOVRE1)                  GUNNO740
C     CALL ZEROA(200,DS,FORCE,HALFM,HYDRAD,MACHSQ)                      GUNNO741
C     CALL ZEROA(31,INTERJ,INTERJ,INTERJ,INTERJ,INTERJ)                 GUNNO742
      CALL ZEROA(30,OUTBDY,ROZERO,TOVRE1,TOVRE1,TOVRE1)                 GUNNO743
      CALL ZEROA(200,DS,FORCE,HALFM,HYDRAD,HYDRAD)                      GUNNO744
      DC 52 IA=1,200                                                    GUNNO745
   52 MACHSQ(IA)=0                                                      GUNNO746
      DO 54 IB=1,30                                                     GUNNO747
      NEQST(IB)=0                                                       GUNNO748
      NZONES(IB)=0                                                      GUNNO749
   54 INTERJ(IB)=0                                                      GUNNO750
      INTERJ(31)=0                                                      GUNNO751
      CALL ZEROA(200,PPLUSQ,SKIN,TSIGSQ,THETA,VISCOS)                   GUNNO752
      CALL ZEROA(2,TMINSQ,TMINSQ,TMINSQ,TMINSQ,TMINSQ)                  GUNNO753
      CALL ZEROA(30,VZERO,UZERO,UZERO,UZERO,UZERO)                      GUNNO754
      CALL ZEROA(201,USQ,USQ,USQ,USQ,USQ)                               GUNNO755
      CALL ZEROA(200,X1,ZMASS,X1,X1,X1)                                 GUNNO756
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      CALL ZEROB(E,200,2)                                             GUNN0757
      CALL ZEROB(AREA,200,2)                                          GUNN0758
      CALL ZEROB(Q,200,2)                                             GUNN0759
      CALL ZEROB(U,201,2)                                             GUNN0760
      CALL ZEROB(V,200,2)                                             GUNN0761
      CALL ZEROB(P,200,2)                                             GUNN0762
      CALL ZEROB(X,201,2)                                             GUNN0763
      RETURN                                                          GUNN0764
      END                                                             GUNN0765
      SUBROUTINE IERO(I1,I2,I3,I4,I5,I6,I7,I8)                        GUNN0766
C     ZEROS INTEGERS                                                  GUNN0767
      I1=0                                                            GUNN0768
      I2=0                                                            GUNN0769
      I3=0                                                            GUNN0770
      I4=0                                                            GUNN0771
      I5=0                                                            GUNN0772
      I6=0                                                            GUNN0773
      I7=0                                                            GUNN0774
      I8=0                                                            GUNN0775
      RETURN                                                          GUNN0776
      END                                                             GUNN0777
      SUBROUTINE ZERO(Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8)                        GUNN0778
C     ZEROS NON-INTEGERS                                              GUNN0779
      Z1=0.                                                           GUNN0780
      Z2=0.                                                           GUNN0781
      Z3=0.                                                           GUNN0782
      Z4=0.                                                           GUNN0783
      Z5=0.                                                           GUNN0784
      Z6=0.                                                           GUNN0785
      Z7=0.                                                           GUNN0786
      Z8=0.                                                           GUNN0787
      RETURN                                                          GUNN0788
      END                                                             GUNN0789
      SUBROUTINE ZEROA(IZA,ZA1,ZA2,ZA3,ZA4,ZA5)                       GUNN0790
C     ZEROS VECTORS                                                   GUNN0791
      DIMENSION  ZA1(300),ZA2(300),ZA3(300),ZA4(300),ZA5(300)         GUNN0792
      DO 1  IZZ=1, IZA                                                GUNN0793
      ZA1(IZZ)=0.                                                     GUNN0794
      ZA2(IZZ)=0.                                                     GUNN0795
      ZA3(IZZ)=0.                                                     GUNN0796
      ZA4(IZZ)=0.                                                     GUNN0797
      ZA5(IZZ)=0.                                                     GUNN0798
    1 CONTINUE                                                        GUNN0799
      RETURN                                                          GUNN0800
      END                                                             GUNN0801
      SUBROUTINE ZEROB(ZAB,IZA,JZB)                                   GUNN0802
C     ZEROS ARRAYS                                                    GUNN0803
      DIMENSION ZAB (300,10)                                          GUNN0804
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      DO 2 IZZ=1,IZA                                                    GUNN0805
      DO 1  JZZ=1, JZB                                                  GUNN0806
    1 ZAB(IZZ,JZZ)=0.                                                   GUNN0807
    2 CONTINUE                                                          GUNN0808
      RETURN                                                            GUNN0809
      END                                                               GUNN0810
      SLBROUTINE STORIN  (ISTORM,STORM)                                 GUNN0811
C     STORAGE ROUTINE                                                   GUNN0812
      CCMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        GUNN0813
      CCMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN0814
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNN0815
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  GUNN0816
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,   GUNN0817
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,       GUNN0818
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   GUNN0819
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  GUNN0820
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNN0821
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GUNN0822
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  GUNN0823
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     GUNN0824
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  GUNN0825
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN0826
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN0827
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNN0828
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN0829
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  GUNN0830
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNN0831
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN0832
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNN0833
      DIMENSION ISTORM(100), STORM(100)                                 GUNN0834
      JPROJ=0                                                           GUNN0835
      IDUM=0                                                            GUNN0836
      PVWANT=0.                                                         GUNN0837
      PVSLPE=0.                                                         GUNN0838
      PRESCG=0.                                                         GUNN0839
      PVERR=0.                                                          GUNN0840
      XPV2=0.                                                           GUNN0841
      XPV1=0.                                                           GUNN0842
      ISTORM( 1) = IMAX                                                 GUNN0843
      ISTORM( 2) = NDATE1                                               GUNN0844
      ISTORM( 3) = NDATE2                                               GUNN0845
      ISTORM( 4) = NDATE3                                               GUNN0846
      ISTORM( 5) = NUMBER                                               GUNN0847
      ISTORM( 6) = NCHEKE                                               GUNN0848
      ISTORM( 7) = INU                                                  GUNN0849
      ISTORM( 8) = JPROJ                                                GUNN0850
      ISTORM( 9) = IHEL                                                 GUNN0851
      ISTORM(10) = IDUM                                                 GUNN0852
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      DO 1 IN=1,     IMAX                                              GUNN0853
      IN10=IN+10                                                       GUNN0854
      IN20=IN+20                                                       GUNN0855
      IN30=IN+30                                                       GUNN0856
      IN40=IN+40                                                       GUNN0857
      IN50=IN+50                                                       GUNN0858
      IN60=IN+60                                                       GUNN0859
      ISTORM( IN10)= NEQST(IN)                                         GUNN0860
      ISTORM( IN20)= NZONES(IN)                                        GUNN0861
      STORM(IN)= OUTBDY(IN)                                            GUNN0862
      STORM(IN10)= GAMMA(IN)                                           GUNN0863
      STORM(IN20)= CQSQX4(IN)                                          GUNN0864
      STORM(IN30)= UZERO(IN)                                           GUNN0865
      STORM(IN40)= PO (IN)                                             GUNN0866
      STORM(IN50)= TO (IN)                                             GUNN0867
      STORM(IN60)= AMOL(IN)                                            GUNN0868
    1 CONTINUE                                                         GUNN0869
      STORM(71)=AREA1                                                  GUNN0870
      STORM(72)=AREA2                                                  GUNN0871
      STORM(73)=AREA3                                                  GUNN0872
      STORM(74)=PCON1                                                  GUNN0873
      STORM(75)=PCON2                                                  GUNN0874
      STORM(76)=SHPR                                                   GUNN0875
      STORM(77)=EMPROJ                                                 GUNN0876
      STORM(78)=OUTDT1                                                 GUNN0877
      STORM(79)=TMAX1                                                  GUNN0878
      STORM(80)=OUTDT2                                                 GUNN0879
      STORM(81)=TMAX2                                                  GUNN0880
      STORM(82)=XSTOP                                                  GUNN0881
      STORM(83)=PCON3                                                  GUNN0882
      STORM(84)=SLOPE                                                  GUNN0883
      STORM(85)=RADIUS                                                 GUNN0884
      STORM(86)=CALPGM                                                 GUNN0885
      STORM(87)=TBURND                                                 GUNN0886
      STORM(88)=GMSPDR                                                 GUNN0887
      STORM(89)=GASPRS                                                 GUNN0888
      STORM(90)=R                                                      GUNN0889
      STORM(91)=EMPIST                                                 GUNN0890
      STORM(92)=PVWANT                                                 GUNN0891
      STORM(93)=PVSLPE                                                 GUNN0892
      STORM(94)=XPV1                                                   GUNN0893
      STORM(95)=XPV2                                                   GUNN0894
      STORM(96)=PVERR                                                  GUNN0895
      STORM(97)= PRESCG                                                GUNN0896
      RETURN                                                           GUNN0897
      END                                                              GUNN0898
      SUBROUTINE  STORE (ISTORM, STORM)                                GUNN0899
C     STORAGE ROUTINE                                                  GUNN0900
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      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        GUNNO901
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNNO902
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNNO903
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, GUNNO904
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,   GUNNO905
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,       GUNNO906
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   GUNNO907
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  GUNNO908
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNNO909
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GUNNO910
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  GUNNO911
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     GUNNO912
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  GUNNO913
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNNO914
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNNO915
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNNO916
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNNO917
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  GUNNO918
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNNO919
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNNO920
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNNO921
      DIMENSION ISTORM(100), STORM(100)                                 GUNNO922
      IMAX   = ISTORM(1)                                                GUNNO923
      NDATE1= ISTORM(2)                                                 GUNNO924
      NDATE2= ISTORM(3)                                                 GUNNO925
      NDATE3= ISTORM(4)                                                 GUNNO926
      NUMBER= ISTORM(5)                                                 GUNNO927
      NCHEKE= ISTORM(6)                                                 GUNNO928
      INU    = ISTORM(7)                                                GUNNO929
      JPROJ  = ISTORM(8)                                                GUNNO930
      IHEL   = ISTORM(9)                                                GUNNO931
      IDUM   = ISTORM(10)                                               GUNNO932
      DO 1 IN=1, IMAX                                                   GUNNO933
      IN10=IN + 10                                                      GUNNO934
      IN20=IN + 20                                                      GUNNO935
      IN30=IN + 30                                                      GUNNO936
      IN40=IN + 40                                                      GUNNO937
      IN50=IN + 50                                                      GUNNO938
      IN60=IN + 60                                                      GUNNO939
      NEQST(IN)= ISTORM(IN10)                                           GUNNO940
      NZONES(IN)=ISTORM(IN20)                                           GUNNO941
      OUTBDY(IN)=STORM(IN)                                              GUNNO942
      GAMMA (IN)=STORM(IN10)                                            GUNNO943
      CQSQX4(IN)=STORM(IN20)                                            GUNNO944
      UZERO (IN)=STORM(IN30)                                            GUNNO945
      PO    (IN)=STORM(IN40)                                            GUNNO946
      TO    (IN)=STORM(IN50)                                            GUNNO947
      AMOL  (IN)=STORM(IN60)                                            GUNNO948
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1 CONTINUE                                                              GUNN0949
  AREA1 =  STORM(71)                                                   GUNN0950
  AREA2 =  STORM(72)                                                   GUNN0951
  AREA3 =  STORM(73)                                                   GUNN0952
  PCON1 =  STORM(74)                                                   GUNN0953
  PCON2 =  STORM(75)                                                   GUNN0954
  SHPR  =  STORM(76)                                                   GUNN0955
  EMPROJ=  STORM(77)                                                   GUNN0956
  DLTDT1=  STORM(78)                                                   GUNN0957
  TMAX1 =  STORM(79)                                                   GUNN0958
  DLTDT2=  STORM(80)                                                   GUNN0959
  TMAX2 =  STORM(81)                                                   GUNN0960
  XSTOP =  STORM(82)                                                   GUNN0961
  PCON3 =  STORM(83)                                                   GUNN0962
  SLOPE =  STORM(84)                                                   GUNN0963
  RADIUS=  STORM(85)                                                   GUNN0964
  CALPGM=  STORM(86)                                                   GUNN0965
  TBURND=  STORM(87)                                                   GUNN0966
  GMSPDR=  STORM(88)                                                   GUNN0967
  GASPRS=  STORM(89)                                                   GUNN0968
  R     =  STORM(90)                                                   GUNN0969
  EMPIST=  STORM(91)                                                   GUNN0970
  PVWANT=STORM(92)                                                     GUNN0971
  PVSLPE=STORM(93)                                                     GUNN0972
  XPV1=STORM(94)                                                       GUNN0973
  XPV2=STORM(95)                                                       GUNN0974
  PVERR=STORM(96)                                                      GUNN0975
  PRESCG=STORM(97)                                                     GUNN0976
  RETURN                                                               GUNN0977
  END                                                                  GUNN0978
  SUBROUTINE GENSUB                                                    GUNN0979
C SETS EQUATION PARAMETERS TO INITIAL CONDITIONS                       GUNN0980
  COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL            GUNN0981
  COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN0982
 1,DTMIN,CUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,CMU,DPDE,GUNN0983
 2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  GUNN0984
 3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GUNN0985
 4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        GUNN0986
 5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    GUNN0987
 6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   GUNN0988
 7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      GUNN0989
  COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   GUNN0990
 1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   GUNN0991
 2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      GUNN0992
 3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GUNN0993
  DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN0994
 1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN0995
 2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         GUNN0996
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     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN0997
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   GUNN0998
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   GUNN0999
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN1000
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    GUNN1001
      DC 35 I=1,IMAX                                                      GUNN1002
   35 HALFRO(I)=ROZERO(I)/2.                                              GUNN1003
      INTERJ(1)=1                                                         GUNN1004
      DO 40 I=1,IMAX                                                      GUNN1005
   40 INTERJ(I+1)=INTERJ(I)+NZONES(I)                                     GUNN1006
      JLAST=INTERJ(IMAX+1)                                                GUNN1007
      JLAST1=JLAST-1                                                      GUNN1008
      DJLAST=JLAST                                                        GUNN1009
      DLAST1=JLAST1                                                       GUNN1010
      DNZCNE=NZONES(1)                                                    GUNN1011
      DELX(1)=OUTBDY(1)/DNZONE                                            GUNN1012
      X(1,N)=0.                                                           GUNN1013
      U(1,NMNHAF)=UZERO(1)                                                GUNN1014
      DC 45 I=2,IMAX                                                      GUNN1015
      DNZONE=NZONES(I)                                                    GUNN1016
   45 DELX(I)=(OUTBDY(I)-OUTBDY(I-1))/DNZONE                              GUNN1017
      DC 55 I=1,IMAX                                                      GUNN1018
      JMIN=INTERJ(I)+1                                                    GUNN1019
      JMAX=INTERJ(I+1)-1                                                  GUNN1020
      DC 50 J=JMIN,JMAX                                                   GUNN1021
      JMNHAF=J-1                                                          GUNN1022
      U(J,NMNHAF)=UZERO(I)                                                GUNN1023
      V(JMNHAF,N)=VZERO(I)                                                GUNN1024
      E(JMNHAF,N)=EZERO(I)                                                GUNN1025
   50 X(J,N)=X(J-1,N)+DELX(I)                                             GUNN1026
      X(JMAX+1,N)=OUTBDY(I)                                               GUNN1027
      U(JMAX+1,NMNHAF)=UZERO(I)                                           GUNN1028
      E(JMAX,N)=EZERO(I)                                                  GUNN1029
   55 V(JMAX,N)=VZERO(I)                                                  GUNN1030
      DO 132 J=1,JLAST                                                    GUNN1031
  132 CALL ARCOMP                                                         GUNN1032
   65 DO 130 I=1,IMAX                                                     GUNN1033
      JMIN=INTERJ(I)+1                                                    GUNN1034
      JMAX=INTERJ(I+1)                                                    GUNN1035
      DO 125 J=JMIN,JMAX                                                  GUNN1036
      JMNHAF=J-1                                                          GUNN1037
  120 CALL VCOMP                                                          GUNN1038
      HALFM(JMNHAF)=HALFRO(I)/V(JMNHAF,N)*VOLUME                          GUNN1039
  125 CCNTINUE                                                            GUNN1040
      HALFM(JLAST)=HALFM(JLAST)+EMPROJ                                    GUNN1041
      INDEX=NEQST(I)                                                      GUNN1042
      IF(INDEX.EQ.1)CALL ECST1                                            GUNN1043
      IF(INDEX.EQ.2)CALL ECST2                                            GUNN1044
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      IF(INDEX.EQ.3)CALL EQST3                                          GUNN1045
  130 CONTINUE                                                          GUNN1046
      DO 135  JMNHAF=1,JLAST1                                           GUNN1047
  135 PPLUSQ(JMNHAF)=P(JMNHAF,N)                                        GUNN1048
  150 DK=1.                                                             GUNN1049
      DK1=2.                                                            GUNN1050
  155 EINSUM=0.                                                         GUNN1051
      EKSUM=0.                                                          GUNN1052
      ETOT=0.                                                           GUNN1053
      USQ(1)=U(1,N)**2                                                  GUNN1054
      DO 165  I=1,IMAX                                                  GUNN1055
      EINT(I)=0.                                                        GUNN1056
      EKIN(I)=0.                                                        GUNN1057
      JMIN=INTERJ(I)                                                    GUNN1058
      JMAX=INTERJ(I+1)-1                                                GUNN1059
      DO 160  J=JMIN,JMAX                                               GUNN1060
      JPLHAF=J                                                          GUNN1061
      USQ(J+1)=U(J+1,N)**2                                              GUNN1062
      EINT(I)=EINT(I)+E(JPLHAF,N)/HALFRO(I)*HALFM(JPLHAF)*DK            GUNN1063
  160 EKIN(I)=(USQ(J)+USQ(J+1))*HALFM(JPLHAF)*DK+EKIN(I)                GUNN1064
      EKIN(I)=.5*EKIN(I)                                                GUNN1065
      EINSUM=EINSUM+EINT(I)                                             GUNN1066
  165 EKSUM=EKSUM+EKIN(I)                                               GUNN1067
      ETOT=EINSUM+EKSUM                                                 GUNN1068
      ESUM=ETOT                                                         GUNN1069
      ETENTH=.1*ETOT                                                    GUNN1070
  175 XGRID=.125*(X(JMAX,N)-X(1,N))                                     GUNN1071
      XMIN=X(1,N)-XGRID                                                 GUNN1072
      XMAX=X(JMAX,N)+XGRID                                              GUNN1073
  180 CALL OUTPUT                                                       GUNN1074
      RETURN                                                            GUNN1075
      END                                                               GUNN1076
      SUBROUTINE DYNMEQ                                                 GUNN1077
C     CALCULATES MASS POINT VELOCITY AND ZONE SPECIFIC VOLUME AND       GUNN1078
C     BOUNDARIES                                                        GUNN1079
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        GUNN1080
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN1081
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNN1082
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, GUNN1083
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,   GUNN1084
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERC,SHPR,       GUNN1085
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   GUNN1086
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  GUNN1087
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNN1088
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GUNN1089
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  GUNN1090
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     GUNN1091
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  GUNN1092
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      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN1093
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN1094
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        GUNN1095
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN1096
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  GUNN1097
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNN1098
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN1099
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   GUNN1100
C 120 I=1                                                               GUNN1101
  120 CCNTINUE                                                          GUNN1102
  125 DLAMAX=0.                                                         GUNN1103
      SIGMAX=0.                                                         GUNN1104
      T=T+DTMIN(NPLHAF)                                                 GUNN1105
      NCYCLE=NCYCLE+1                                                   GUNN1106
  150 DO 245 I=1,IMAX                                                   GUNN1107
      NZN=NZONES(I+1)                                                   GUNN1108
      CMAXR(I)=0.                                                       GUNN1109
      CSCMAX=0.                                                         GUNN1110
      JMIN=INTERJ(I)+1                                                  GUNN1111
      JMAX=INTERJ(I+1)                                                  GUNN1112
      DO 230 J=JMIN,JMAX                                                GUNN1113
      JPLHAF=J                                                          GUNN1114
      JMNHAF=J-1                                                        GUNN1115
  361 IF(JLAST-J) 155,155,1700                                          GUNN1116
  155 DUDT=PPLUSQ(JMNHAF)*AREA(JLAST,N)/HALFM(JMNHAF)                   GUNN1117
      IF(JPROJ.EQ.300.AND.E(JMNHAF,N) .NE.0.0)  GC TO 195               GUNN1118
      GO TO 901                                                         GUNN1119
 1700 IF(JPROJ.EQ.300) GO TO 1755                                       GUNN1120
      IF(J.EQ.INTERJ(6)) GO TO 901                                      GUNN1121
      IF(J.GT.INTERJ(6)) GO TO 902                                      GUNN1122
      GC TO 1755                                                        GUNN1123
  901 IF(PPLUSQ(JMNHAF)-SHPR) 902,903,903                               GUNN1124
  902 U(J,NPLHAF)=0.0                                                   GUNN1125
      GC TO 196                                                         GUNN1126
  903 JPROJ=500                                                         GUNN1127
      DTSQ(200)=T                                                       GUNN1128
 1755 IF(J.EQ.JMAX.AND.NZN.EQ.1) GO TO 876                              GUNN1129
      IF(J.EQ.JMAX.AND.NZN.GT.1) GO TO 800                              GUNN1130
      DUDT=(PPLUSQ(JMNHAF)-PPLUSQ(JPLHAF))*AREA(J,N)/(HALFM(JMNHAF)+    GUNN1131
     1HALFM(JPLHAF))                                                    GUNN1132
      GC TO 195                                                         GUNN1133
  800 IF(J.EQ.INTERJ(6)) GO TO 863                                      GUNN1134
      DUDT =-(1.5*(PPLUSQ(JPLHAF)-PPLUSQ(JMNHAF))-(PPLUSQ(JPLHAF+1)-    GUNN1135
     1 PPLUSQ(JMNHAF-1))/6.)*AREA(J,N)/(HALFM(JMNHAF)+HALFM(JPLHAF))    GUNN1136
      GC TO 195                                                         GUNN1137
  863 DUDT =-(1.5*(PPLUSQ(JPLHAF)-PPLUSQ(JMNHAF))-(PPLUSQ(JPLHAF+1)-    GUNN1138
     1  (PPLUSQ(JMNHAF)/3.+2.*PPLUSQ(JMNHAF-1)/3.)                      GUNN1139
     1 )/6.)*AREA(J,N)/(HALFM(JMNHAF)+HALFM(JPLHAF))                    GUNN1140
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      IF(T.GE.(DTSQ(200)+DTSQ(199))) GO TO 194
      DUDT=DUDT*(T-DTSQ(200))/DTSQ(199)
  194 CONTINUE
      GO TO 195
  876 A=2.*HALFM(JMNHAF)
      B=HALFM(JMNHAF)+HALFM(JPLHAF)
      DUDT=((2.*A**2*PPLUSQ(JPLHAF))
     1-(2.*A-B)*(A+B)*PPLUSQ(LMNHAF)
     2+(A-B)*B*PPLUSQ(JMNHAF-1))/(A*(A+B)*B)*(-1.)*AREA(J,N)
  195 U(J,NPLHAF)=U(J,NMNHAF)+DTMIN(NN)*DUDT
  196 X(J,NPLUS1)=X(J,N)+DTMIN(NPLHAF)*U(J,NPLHAF)
      CALL ARCOMP
      CALL VCOMP
      V(JMNHAF,NPLUS1)=HALFRO(I)/HALFM(JMNHAF)*VOLUME
  200 IF(U(J,NPLHAF)-U(J-1,NPLHAF)) 205,225,225
  205 Q(JMNHAF,NPLHAF)=CQSQX4(I)*HALFRO(I)*(U(J,NPLHAF)-U(J-1,NPLHAF))
     1**2/(V(JMNHAF,NPLUS1)+V(JMNHAF,N))
      GO TO 230
  225 Q(JMNHAF,NPLHAF)=0.
  230 CONTINUE
      INDEX=NEQST(I)
      IF(INDEX.EQ.1)CALL EQST1
      IF(INDEX.EQ.2)CALL EQST2
      IF(INDEX.EQ.3)CALL EQST3
   53 DO 240 J=JMIN,JMAX
      JMNHAF=J-1
      IF(JPROJ.LT.300.AND.J.GT.INTERJ(6)) GO TO 24
      TSIGSQ(JMNHAF)=CSQ(JMNHAF)/(X(J,NPLUS1)-X(J-1,NPLUS1))**2
   24 CONTINUE
      PPLUSQ(JMNHAF)=P(JMNHAF,NPLUS1)+Q(JMNHAF,NPLHAF)
      DLAMDA(JMNHAF)=CQSQX4(I)/2.*(V(JMNHAF,N      )-V(JMNHAF,NPLUS1))/
     1(V(JMNHAF,N)+V(JMNHAF,NPLUS1))
C     CHANGED TO MAX1 JANUARY 16, 1967 DKS
      DLAMAX= MAX1(DLAMDA(JMNHAF),DLAMAX)
      SIGMAX= MAX1(TSIGSQ(JMNHAF),SIGMAX)
      CSQMAX= MAX1(CSQMAX,CSQ(JMNHAF))
      IF ( TSIGSQ(JMNHAF) .NE. 0.0 ) GO TO 240
      DTSQ(JMNHAF) =0.0
      GO TO 245
  240 DTSQ(JMNHAF)=.1111111/TSIGSQ(JMNHAF)
  245 CMAXR(I)=SQRT (CSQMAX)
  340 CONTINUE
  246 RETURN
      END
      SUBROUTINE ARCOMP
C     DETERMINES ZONE CROSS SECTIONAL AREA
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSFDR,GASPRS,IHEL
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAX
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     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNN1189
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, GUNN1190
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GUNN1191
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        GUNN1192
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    GUNN1193
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   GUNN1194
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      GUNN1195
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   GUNN1196
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   GUNN1197
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      GUNN1198
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GUNN1199
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN1200
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN1201
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         GUNN1202
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN1203
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   GUNN1204
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   GUNN1205
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN1206
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    GUNN1207
    2 IF(X(J,NPLUS1)-PCON3) 5,4,4                                        GUNN1208
    4 AREA(J,NPLUS1)=AREA3                                               GUNN1209
      GO TO 10                                                           GUNN1210
    5 IF(X(J,NPLUS1)-PCON2) 7,6,6                                        GUNN1211
    6 AREA(J,NPLUS1)=AREA2                                               GUNN1212
      GO TO 10                                                           GUNN1213
    7 IF(X(J,NPLUS1)-PCON1) 9,8,8                                        GUNN1214
    8 AREA(J,NPLUS1)=AREA2                                               GUNN1215
      GO TO 10                                                           GUNN1216
    9 AREA(J,NPLUS1)=AREA1                                               GUNN1217
   10 RETURN                                                             GUNN1218
      END                                                                GUNN1219
      SUBROUTINE VCOMP                                                   GUNN1220
C     DETERMINES ZONE VOLUME                                             GUNN1221
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL         GUNN1222
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN1223
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNN1224
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, GUNN1225
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GUNN1226
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        GUNN1227
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    GUNN1228
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   GUNN1229
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      GUNN1230
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   GUNN1231
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   GUNN1232
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      GUNN1233
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GUNN1234
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN1235
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN1236
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      2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),       GUNN1237
      3FALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN1238
      4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  GUNN1239
      5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  GUNN1240
      6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN1241
      7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                  GUNN1242
       XPV1=0.                                                          GUNN1243
       XPV2=0.                                                          GUNN1244
       PVERR=0.                                                         GUNN1245
       PRESCG=0.                                                        GUNN1246
     2 IF(X(J,NPLUS1)-PCON1) 3,3,4                                      GUNN1247
     3 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA1                         GUNN1248
       GO TO 17                                                         GUNN1249
     4 IF(X(J,NPLUS1)-PCON2) 5,5,8                                      GUNN1250
     5 IF(X(J-1,NPLUS1)-PCON1) 6,7,7                                    GUNN1251
     6 VOLUME=(X(J,NPLUS1)-PCON1)*AREA2+(PCON1-X(J-1,NPLUS1))*AREA1     GUNN1252
       GO TO 17                                                         GUNN1253
     7 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2                         GUNN1254
       GO TO 17                                                         GUNN1255
     8 IF(X(J,NPLUS1)-PCON3) 9,9,12                                     GUNN1256
     9 IF(X(J-1,NPLUS1)-PCON2) 10,11,11                                 GUNN1257
    10 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2                         GUNN1258
       GO TO 17                                                         GUNN1259
    11 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2                         GUNN1260
       GO TO 17                                                         GUNN1261
    12 IF(X(J-1,NPLUS1)-PCON3) 14,13,13                                 GUNN1262
    13 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3                         GUNN1263
       GO TO 17                                                         GUNN1264
    14 IF(X(J-1,NPLUS1)-PCON2) 16,15,15                                 GUNN1265
    15 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3                         GUNN1266
       GO TO 17                                                         GUNN1267
    16 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3                         GUNN1268
    17 RETURN                                                           GUNN1269
       END                                                              GUNN1270
       SUBROUTINE EQST1                                                 GUNN1271
C      CALCULATES PRESSURE AND ENERGY FOR IDEAL GAS ZONES               GUNN1272
       COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL       GUNN1273
       COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN1274
      1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,CMU,DPDE,GUNN1275
      2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, GUNN1276
      3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,   GUNN1277
      4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,       GUNN1278
      5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   GUNN1279
      6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  GUNN1280
      7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     GUNN1281
       COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GUNN1282
      1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NCATE1,NCATE2,  GUNN1283
      2NCATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     GUNN1284
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      3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GUNN1285
       DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN1286
      1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN1287
      2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         GUNN1288
      3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN1289
      4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   GUNN1290
      5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   GUNN1291
      6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN1292
      7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    GUNN1293
       JMIN1=JMIN-1                                                       GUNN1294
       JMAX1=JMAX-1                                                       GUNN1295
       DO 10 JMNHAF=JMIN1,JMAX1                                           GUNN1296
       E1=E(JMNHAF,N)-(P(JMNHAF,N)+Q(JMNHAF,NPLHAF))*(V(JMNHAF,NPLUS1)-   GUNN1297
      1V(JMNHAF,N))                                                       GUNN1298
       P1=E1*(GAMMA(I)-1.0)/ V(JMNHAF,NPLUS1)                             GUNN1299
       E(JMNHAF,NPLUS1)=E1-.5*(P1-P(JMNHAF,N))*(V(JMNHAF,NPLUS1)-         GUNN1300
      1V(JMNHAF,N))                                                       GUNN1301
       P(JMNHAF,NPLUS1)=E(JMNHAF,NPLUS1)*(GAMMA(I)-1.0)/ V(JMNHAF,NPLUS1)GUNN1302
 10    CSQ(JMNHAF)=GAMMA(I)*(GAMMA(I)-1.0)*E(JMNHAF,NPLUS1)/ROZERO(I)     GUNN1303
       RETURN                                                             GUNN1304
       END                                                                GUNN1305
       SUBROUTINE EQST2                                                   GUNN1306
C      CALCULATES PRESSURE AND ENERGY FOR NON-IDEAL GAS ZONES             GUNN1307
       COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL         GUNN1308
       COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGUNN1309
      1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GUNN1310
      2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  GUNN1311
      3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GUNN1312
      4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        GUNN1313
      5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    GUNN1314
      6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   GUNN1315
      7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      GUNN1316
       COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   GUNN1317
      1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   GUNN1318
      2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      GUNN1319
      3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GUNN1320
       DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GUNN1321
      1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GUNN1322
      2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         GUNN1323
      3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GUNN1324
      4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   GUNN1325
      5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   GUNN1326
      6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GUNN1327
      7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    GUNN1328
       IF(NCYCLE.EQ.1)T=0.0                                               GUNN1329
       IF(T.GT..0000001)GO TO 3                                           GUNN1330
       IF(INTERJ(30))3,1,3                                                GUNN1331
     1 NCHEKE=0                                                           GUNN1332
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      IBURND=0                                                          GUNN1333
      TOLD=0.                                                           GUNN1334
      INTERJ(30)=2                                                      GUNN1335
      ZMASS(200)=2.                                                     GUNN1336
      GASPRS=GASPRS/14.5                                                GUNN1337
      PVOL=GMSPDR/1000.                                                 GUNN1338
      GVOL=PCON1*AREA1*.001-PVOL                                        GUNN1339
      GMOLES=GASPRS*GVOL/24.61                                          GUNN1340
      PMOLES=GMSPDR/25.                                                 GUNN1341
      PRESUR=(GMOLES+PMOLES)*24.61/(GVOL+PVOL)*1.0138                   GUNN1342
      IF(IHEL)40,40,35                                                  GUNN1343
   35 GAMMA(I)=(GMOLES*1.667+PMOLES*1.23)/(GMOLES+PMOLES)               GUNN1344
      WGTMOL=(GMOLES*4.0026+PMOLES*25.)/(GMOLES+PMOLES)                 GUNN1345
      GO TO 50                                                          GUNN1346
   40 GAMMA(I)=(GMOLES*1.4+PMOLES*1.23)/(GMOLES+PMOLES)                 GUNN1347
      WGTMOL=(GMOLES*2.+PMOLES*25.)/(GMOLES+PMOLES)                     GUNN1348
   50 SPCVOL=83.17*300.0/(PRESUR*WGTMOL)                                GUNN1349
      ROZERO(I)=WGTMOL/22400.                                           GUNN1350
      VZERO(I)=SPCVOL*ROZERO(I)                                         GUNN1351
      EZERO(I)=PRESUR*VZERO(I)/(GAMMA(I)-1.)                            GUNN1352
      JMIN1=JMIN-1                                                      GUNN1353
      JMAX1=JMAX-1                                                      GUNN1354
      DO 20 J=JMIN1,JMAX1                                               GUNN1355
      E(J,N)=EZERO(I)                                                   GUNN1356
   20 V(J,N)=VZERO(I)                                                   GUNN1357
      EPEAK=CALPGM*41.84*ROZERO(I)*PMOLES*25.0/(PMOLES*25.0+GMOLES*2.0) GUNN1358
      HALFRO(I)=ROZERO(I)/2.                                            GUNN1359
      DO 30 J=JMIN,JMAX                                                 GUNN1360
      VOLUME=(X(J,N)-X(J-1,N))*AREA1                                    GUNN1361
   30 HALFM(J-1)=HALFRO(I)/V(J-1,N)*VOLUME                              GUNN1362
    3 JMIN1=JMIN-1                                                      GUNN1363
      JMAX1=JMAX-1                                                      GUNN1364
      IF(IBURND)4,4,7                                                   GUNN1365
    4 IF ( TBURND .EQ. 0.0 ) GO TO 6                                    GUNN1366
C     STATEMENT IF ( TBURND .EQ. 0.0 ). GO TO 6 WAS INSERTED DURING CON- GUNN1367
C     VERSION TO THE G.E. 635                                           GUNN1368
      IF(TBURND-T)6,5,5                                                 GUNN1369
    5 DELE=EPEAK*(T-TOLD)/TBURND                                        GUNN1370
      TOLD=T                                                            GUNN1371
      GO TO 7                                                           GUNN1372
    6 DELE=0.                                                           GUNN1373
      IBURND=1                                                          GUNN1374
    7 DO 10 JMNHAF=JMIN1,JMAX1                                          GUNN1375
      E1=E(JMNHAF,N)-(P(JMNHAF,N)+Q(JMNHAF,NPLHAF))* (V(JMNHAF,NPLUS1)- GUNN1376
     1V(JMNHAF,N))+DELE                                                 GUNN1377
      P1=(GAMMA(I)-1.)*E1/V(JMNHAF,NPLUS1)                              GUNN1378
      E(JMNHAF,NPLUS1)=E1-.5*(P1-P(JMNHAF,N))*(V(JMNHAF,NPLUS1)-        GUNN1379
     1V(JMNHAF,N))                                                      GUNN1380
```

```
      P(JMNHAF,NPLUS1)=(GAMMA(I)-1.)*E(JMNHAF,NPLUS1)/V(JMNHAF,NPLUS1)
   10 CSQ(JMNHAF)=GAMMA(I)*(GAMMA(I)-1.)*E(JMNHAF,NPLUS1)/ROZERO(I)
      RETURN
      END
      SUBROUTINE EQST3
C     CALCULATES PRESSURE AND ENERGY FOR SOLID ZONES
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAX
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERC,SHPR,
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)
      JMIN1=JMIN-1
      JMAX1=JMAX-1
      DO 10 JMNHAF=JMIN1,JMAX1
      DMU=1./V(JMNHAF,NPLUS1)-1.
      E1=E(JMNHAF,N)-(P(JMNHAF,N)+Q(JMNHAF,NPLHAF))*(V(JMNHAF,NPLUS1)-
     1V(JMNHAF,N))
      DPDMU=21297.0*(DMU+1.0)**6-3041.4
      P(JMNHAF,NPLUS1)=3042.4*(DMU+1.0)**7-3041.4
      IF(P(JMNHAF,NPLUS1)+3000.) 9,11,11
    9 P(JMNHAF,NPLUS1)=-3000.
   11 E(JMNHAF,NPLUS1)=E1-.5*(P(JMNHAF,NPLUS1)-P(JMNHAF,N))*(V(JMNHAF,
     1NPLUS1)-V(JMNHAF,N))
   10 CSQ(JMNHAF)=DPDMU/ROZERO(I)
      RETURN
      END
      SUBROUTINE PVCHNG (PVW, ERR, VEL,PLOAD, GAS, AVEL, ALOAD, AGAS,NU)
      DIMENSION GAS(30), AVEL(100), ALOAD(100), AGAS(100)
      PVLO = 10.
      PVHI = 5000.
      DO 20  N = 1, NU
      IF (AGAS(N).NE.GAS(3)) GO TO 20
```

```
      IF (ABS(AVEL(N)-PVW).LT.ERR) GO TO 30                             GUNN1429
      IF (AVEL(N).GT.PVW.AND.AVEL(N).GT.PVHI)  GO TO 20                 GUNN1430
      IF (AVEL(N).LT.PVW.AND.AVEL(N).LT.PVLO)  GO TO 20                 GUNN1431
      IF (AVEL(N).LT.PVW) GO TO 40                                      GUNN1432
      HILOAD=ALOAD(N)                                                   GUNN1433
      PVHI  =AVEL (N)                                                   GUNN1434
      GO TO 20                                                          GUNN1435
   40 BALOAD = ALOAD (N)                                                GUNN1436
      PVLO  =AVEL (N)                                                   GUNN1437
   20 CONTINUE                                                          GUNN1438
      IF(PVLO.EQ.10..OR.PVHI.EQ.5000.) GO TO 60                         GUNN1439
      PLOAD=BALOAD+(PVW-PVLO)*(BALOAD-HILOAD)/(PVLO-PVHI)               GUNN1440
      GO TO 50                                                          GUNN1441
   30 PLOAD=ALOAD(N)                                                    GUNN1442
      GO TO 50                                                          GUNN1443
   60 PLOAD= PLOAD +(PVW-VEL)* 20.                                      GUNN1444
   50 GAS(1)=PLOAD                                                      GUNN1445
      RETURN                                                            GUNN1446
      END                                                               GUNN1447
```

INPUT FORMAT

```
CARD 1   (4I3,FI0.0)
     IDATA = 0, STANDARD 18 CARD INPUT
           = NAMELIST INPUT OF ALL VARIABLES ON CARDS
     IPRNTZ = 0, STANDARD RUN
            = 1, PRINT OUT INITIAL DATA ONLY
     INTRNSF = 0, USE DISK SCRATCH FILE AND PRINT OUT ONLY LAST PISTON ITERATION
             = 1, PRINT OUT ALL PISTON ITERATIONS (HYPERVELOCITY MODEL ONLY)
     IPUNCH = 0, NO PUNCHED OUTPUT
            = 1, PUNCHED OUTPUT OF MODEL BASE PRESSURE VS TIME
     DTSQ(199)     FINITE BREAK VALVE OPENING TIME

CARD 2   (20I3)
     IMAX = NUMBER OF REGIONS (UP TO SIX)
     NDATE1 = MONTH
     NDATE2 = DAY
     NDATE3 = YEAR
     NUMBER = RUN IDENTIFICATION NUMBER
     NCHEKE = 0, NO ENERGY CHECK
            = 1, ENERGY MONITORED AND PROBLEM STOPPED IF THE TOTAL ENERGY
                 CHANGES BY MORE THAN 10%
     INU = 0, ALL ZONES HAVE ZERO INITIAL VELOCITY
         = 1, ALLOWS INITIAL VELOCITY FOR EACH ZONE TO BE READ
     JPROJ = MASS POINT NUMBER OF PROJECTILE
```

```
CARD 3   (20I3)
     NEQST(I) = NUMBER OR INDEX OF EQUATION OF STATE USED IN REGION I

CARD 4   (20I3)
     NZONES(I) = NUMBER OF ZONES IN REGION I

CARD 5   (7F10.0)
     OUTBDY(I) = DISTANCE IN CM TO OUTER INTERFACE OF REGION I

CARD 6   (7F10.0)
     GAMMA(I) = RATION OF SPECIFIC HEATS FOR REGION I

CARD 7   (7F10.0)
     CQSQX4(I) = CONSTANT USED IN ARTIFICIAL VISCOSITY COMPUTATION
                 (GOOD VALUES ARE 4.0 FOR GAS REGION, 9.0 FOR SOLID REGION)

CARD 8   (7F10.0)
     AREA1 = AREA IN SQ CM OF FIRST CONSTANT AREA SECTION (PROGRAM ALLOWS UP TO
             THREE DIFFERENT CONSTANT AREA SECTIONS AND ONE TAPERED SECTION
             BETWEEN THE SECOND AND THIRD CONSTANT AREA SECTIONS)
     AREA2 = AREA IN SQ CM OF SECOND CONSTANT AREA SECTION
     AREA3 = AREA IN SQ CM OF THIRD CONSTANT AREA SECTION
     PCON1 = POSITION IN CM WHERE FIRST AREA CHANGE OCCURS
     SHPR = PROJECTILE RELEASE PRESSURE IN BARS
     EMPROJ = MASS OF PROJECTILE IN GRAMS
```

```
     OUTDT1 = DELTA T FOR PRINTING UP TO TIME TMAX1
     TMAX1 = MILLISECS
     OUTDT2 = DELTA T FOR PRINTING UP TO TIME TMAX2
     TMAX2 = MILLISECS
     XSTOP = POSITION IN CM THAT WHEN THE INTERFACE JSTOP REACHES IT,
             THE PROBLEM IS TERMINATED

CARD 9   (7F10.0)   REQUIRED ONLY IF INU = 1
     UZERO(I) = INITIAL VELOCITY FOR EACH ZONE

CARD 10   (7F10.0)
     PCON = POSITION IN CM WHERE THIRD AREA CHANGE OCCURS
     SLOPE = SLOPE OF CONSTANT TAPERED SECTION
     RADIUS = RADIUS IN CM OF THE CONSTANT AREA SECTION TO THE RIGHT
              OF THE TAPERED SECTION

CARD 11   (4F10.0I4)
     CALPGM = CALORIES PERGRAM OF POWER
     TBURND = TIME TO BURN POWDER
     GMSPDR = GRAMS OF POWDER
     GASPRS = INITIAL GAS PRESSURE IN POWDER REGION
     IHEL = 0  (NOT APPLICABLE TO GUN PROJECT)
```

```
CARD 12   (7F10.0)
     IPOX = 0 ALL PLOTS, ALL PRESSURE POINTS (PLOT ROUTINE  MUST BE INCLUDED)
          = 1 ALL PLOTS, NO PRESSURE POINTS
          = 5 NO PLOTS, NO PRESSURE POINTS
          = 6 ONLY PRESSURE POINTS
     NPOX = NUMBER OF PRESSURE POINTS (UP TO FIVE)
     XPO(I) = X POSITION IN CM OF PRESSURE POINT I

CARD 13   (7F10.0) HYPERVELOCITY MODEL LAUNCHER PARAMETERS, (NOT APPLICABLE
                   TO GUN PROJECT)
     XPV1 = X POSITION IN CM OF FIRST MEASUREMENT POINT OF PISTON VELOCITY
     XPV2 = X POSITION IN CM OF SECOND MEASUREMENT POINT OF PISTON VELOCITY
     PVERR = PISTON VELOCITY ERROR IN FT PER SEC
     PVWANT = DESIRED PISTON VELOCITY IN FT PER SEC

CARD 14   (E10.0, 3F10.0)
     R = 8317E 08   GAS CONSTANT
     EMPIST = MASS OF FIRST PISTON SECTION (HYPERVELOCITY MODEL LAUNCHER ONLY)
     FRAC = 1.0
     EMLEAD = MASS OF SECOND PISTON SECTION (HYPERVELOCITY MODEL LAUNCHER)

CARD 15   (7F10.0)
     PO(I) = INITIAL PRESSURE IN PSI IN REGION I

CARD 16   (7F10.0)
     TO(I) = INITIAL TEMPERATURE IN DEGREES KELVIN IN REGION I
```

CARD 17 (7F10.0)

AMOL(I) = MOLECULAR WEIGHT OF MATERIAL IN REGION I

CARD 18 (I3)

ILASTK = 0, STOP

= 1, CONTINUE FOR NEW RUN

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Thesis 166719
M702 Montgomery
c.1 Application of holographic interferometry to the interior ballistic flow field in the barrel of a twenty millimeter cannon.